Analysis of Summer Temperature Data from Indiana Waters of Lake Michigan, 1983-1992

An Honors Thesis (HONORS 499)

by

Cindy A. Radicker

Ball State University
Muncie, Indiana
April, 1993

Expected date of graduation: May 1993

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ABSTRACT

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The influences of temperature in an aquatic system are reflected in its productivity, species composition, and water quality. Studies of temperature patterns may provide insight to the relative condition of a system with respect to these characteristics. Such studies may also be useful in assessing the effects and potential effects of global climate warming. Summer temperature profile data taken during June through August of 1983 to 1992 at a fish sample location in Lake Michigan near Michigan City, Indiana were analyzed for trends and anomalies. Progressive temperature increases were observed for the summer months, along with occurrences of extreme temperatures likely due to severe weather events. Evidence of thermoclines in the study areas were consistent with the pattern for dimictic lakes like Lake Michigan. No significant warming trends were detectable over the ten-year period.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDIX

INTRODUCTION

Temperature is one of the most important and variable factors in any aquatic system. Thermal patterns and circulations, influenced by climate and weather events, are largely responsible for establishing a system's physical characteristics and biotic composition. Climate warming, due to increased levels of atmospheric gases, is expected to have a sizeable effect on these features, especially in high air-surface interface lotic (i.e. running water) systems (Meisner et al. 1987). In a large lentic, or standing water system like Lake Michigan, the effects of climate warming may be somewhat delayed, but eventual permanent changes in seasonal thermal structure and resulting species composition will take place.

The study of Lake Michigan near-shore fishes, especially the yellow perch *(Perca flavescens)*, has been in progress since 1969. The project is directed by Dr. Thomas S. McComish, with support from Ball State University, the Indiana Department of Natural Resources, the U.S. Department of the Interior, and the U.S. Department of Commerce. Research on yellow perch and other fish, spiny water fleas *(Bythotrephes cederstroemi)*, plankton, and various other major components of the near-shore biota have been the subjects of many graduate and undergraduate theses. To date, no analysis has been completed on temperature profile data collected at sample zones since 1983.

The objectives of this study were to evaluate temperature patterns in near-shore southern Lake Michigan for one site within the study area; determine significant trends and events within the data, and propose explanations for their existence; and seek clues for the future of Lake Michigan as a resource with regard to global warming.

ACKNOWLEDGMENTS

I would like to acknowledge the Ball State University Honors College for approval and support of this undertaking. Thanks also to Kent Hanauer and Steve Shroyer for help in computer applications. Sincere thanks to Dr. Thomas Mc Comish for his patience and motivation in helping me become a competent writer and biologist. Finally, thanks to my parents for love, support, and the enormous gift of a college education.

LITERATURE REVIEW

One of the first topics studied in introductory limnology courses is temperature. Its relationship to habitat availability, species diversity, and productivity are major considerations.

A fundamental principle of temperature with regard to lakes is stratification. The following explanation of this lake feature was summarized from Cole (1983): The phenomenon known as direct stratification results from solar radiation moving downward and being absorbed exponentially into the water column. As a result, the lake becomes divided into three thermal regions. The epilimnion is the warm upper region most influenced by weather and thus subject to the most variability. The hypolimnion, then, is the bottom region of colder and denser water, and between these two regions lies the thermocline. Defined by Birge in 1897, the thermocline denotes a temperature gradient between the two other regions, characterized by a drop of at least one degree Celsius per 1m depth. The thermocline is more generally termed the metalimnion (Bronsted and Wesenberg-Lund 1911), as the area of change between epilimnion and hypolimnion, and thermocline is used to describe the area in the metalimnion where the temperature-decreasing rate is the greatest (Hutchinson 1957). A body of water with uniform temperature from the surface to the bottom, such as often found in shallow ponds in warm climates, is said to be isothermal, or homothermal. Isothermy can also occur periodically in a stratified lake due to periodic wind-mixing, or seasonally in spring and fall due to density changes associated with warming or cooling. The result is known as overturn. It plays an important role in the periodic nutrient cycling vital to biotic composition. Typically, temperate lakes are not permanently isothermic, and therefore are said to exhibit stability. Stability of stratification can be defined as the amount of work required to mix the lake to isothermy and uniform density.

Several types of lakes exhibiting mixing and isothermy have been defined. Lake Michigan is what is termed a dimictic lake. That is, it remains stratified during the summer, due to the depth of the lake, and the inability of solar radiation to penetrate to the bottom. However, as in Lake Erie, by autumn, decreased surface heating and rapid heat loss from the surface to atmosphere effect the temperature decrease in the upper layers of the water (Schertzer et al. 1987). Winter isothermy is then advanced as the temperature of the water column approaches that of maximum density at about 4°C, thereby greatly reducing the density gradient. Wind action can then rapidly distribute heat loss throughout the entire water column (Assel 1986), and autumnal overturn occurs, followed by indirect stratification in winter. The development of ice plays an important role in winter stratification. A solid ice cover may induce inverse stratification, that is, the coldest temperatures on top in the less dense water or ice, with warmer waters lying below the ice (Cole 1983). But as in the case of Lake Michigan, which does not exhibit 100% ice cover, the open water areas will continue their mixing and cooling throughout the winter (Assel 1986). When environmental temperatures begin to increase at the onset of spring, the lake waters will once again begin their mixing, and spring overturn occurs, followed again by direct summer stratification.

Although large dimictic lakes like Lake Michigan consistently display these patterns of stratification, specific weather events may temporarily alter their composition. Schertzer et al. (1987) described the early stages of stratification on Lake Erie as fragile and susceptible to intense wind action associated with storms, inducing complete vertical mixing in some areas. Daily temperature fluctuations are common, and as Seibel and Ayers (1977) pointed out, fluctuations in southeastern Lake Michigan, common in the summer months, are thought to be caused by wind-induced upwellings. During an upwelling, surface winds force near-shore surface waters offshore and replace them with the cooler waters from below (Seibel and Ayers 1977). Other anomalies in the stratification pattern may be caused by internal waves, or temperature seiches. Cole (1983) describes a temperature seiche as a tilting of the thermocline, caused by the pressure of external standing waves. The thermocline is forced downward by the wave crest over it, resulting in large oscillations of amplitude and periodicity.

In the past, analysis of temperature patterns on large systems like Lake Michigan has been difficult and often inaccurate. However, new applications including satellite imagery are making it possible to identify significant thermal patterns of the lake as a whole (Bolgrien and Brooks 1992). Surface temperature imagery, like that used by the Great Lakes Coastwatch program, has potential applications such as thermal front location, circulation pattern analysis, and ice and snow mapping (Schwab et al. 1992). Large scale satellite imagery may also make it possible for scientists to assess thermal changes in lakes with regard to global climate warming.

Increased levels of gases such as carbon dioxide, methane, and nitrous oxide are expected to result in global warming via a phenomenon known as the greenhouse effect. While the environmental ramifications of the greenhouse effect are somewhat speculative, the possible effects on aquatic systems are numerous. A warmer and lengthier summer season may increase the depth of the thermocline, as well as lengthen the period of summer stratification (Magnuson et al. 1990; Regier and Meisner 1990; Schertzer and Sawchuk 1990). This may delay or even prevent overturn, and result in hypoxic or anoxic bottom waters (Gucinski et al. 1990). In the winter, ice cover is expected to be lessened (Meisner et al. 1987), and again, overturn and nutrient cycling may be inhibited if waters are not allowed to cool and mix to isothermy (Gucinski et al. 1990).

On a species level, climate warming may induce changes due to thermal tolerance, disease susceptibility, and synchrony of predator-prey relationships involving such things as biological timing of spawning activity (Gucinski et al. 1990). In addition, increased interspecific competition for changing habitats may reduce productivity and increase mortality among fishes and other organisms (Meisner et al. 1990).

Although it is impossible to predict precisely the effects of climate warming on aquatic systems, there certainly will be effects. Lake Michigan will be influenced and affected by climate warming, although the magnitude of water in the basin and associated energy dynamics will make subtle changes somewhat difficult to recognize.

DESCRIPTION OF STUDY AREA

Sampling during the past decade has taken place in the near-shore, southern waters of Lake Michigan near Michigan city, Indiana. Of three sites designated for the project, only site K, Kintzele Ditch, is considered here (Figure 1). Temperature profiles were taken at the 5m contour parallel to the shoreline when they were part of trawling procedures, and at 10m and 15m contours when part of gillnet sampling. Distance from shore to the 5m contour was approximately 500 meters. Exact sampling zones were as follows (Mc Comish and Mc Keag 1992):

5m trawl:	East end of zone-	Latitude 41deg, 42 min, 56 sec;
		Longitude 86 deg, 56 min, 11 sec
	West end of zone-	Latitude 41 deg, 42 min, 56 sec;
		Longitude 86 deg, 56 min, 94 sec
10m gillnet:	East end of net-	Latitude 41 deg, 42 min, 89 sec;
		Longitude 86 deg, 56 min, 11 sec
	West end of net-	Latitude 41 deg, 42 min, 89 sec;
		Longitude 86 deg, 56 min, 26 sec
15m gillnet:	East end of net-	Latitude 41 deg, 43 min, 03 sec;
		Longitude 86 deg, 56 min, 11 sec
	West end of net-	Latitude 41 deg, 43 min, 03 sec;
		Longitude 86 deg, 56 min, 26 sec

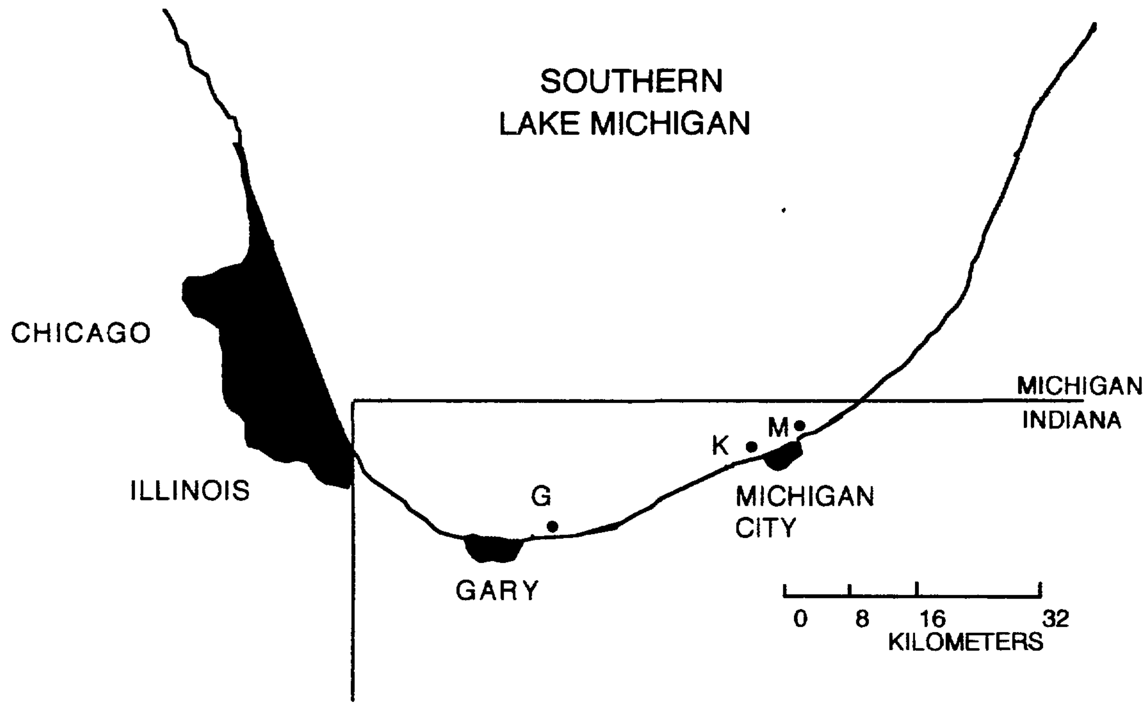


Figure 1. Map showing study area and study site K, Kintzele Ditch.

MATERIALS AND METHODS

Vertical temperature profiles were recorded using a calibrated Yellow Springs Instrument thermometer, according to the method outlined in Lind (1979). Profiles were usually taken twice each month, in most instances more than one week apart. Temperature data were collected during daylight hours, and for the years 1983-1989, were recorded in feet. From 1990 to the present, data have been recorded in meters. For the purposes of this analysis, recordings in feet were converted into meters (1m = 3.3 ft). Profiles were taken from the surface (0.3m or 1 ft.) to the bottom of the sampling site. Because of the size of the sampling area, depths at sample sites varied by sampling method. As a result, depths of profiles between 1983-1992 vary, from 4m to 15m. Sites with depths of 4-7m were treated as "shallow" sites. The data from these sites were plotted as "shallow bottom temperatures." Data from deeper sites were plotted with respect to temperatures at the surface, 5m, and 10m.

RESULTS

Introduction

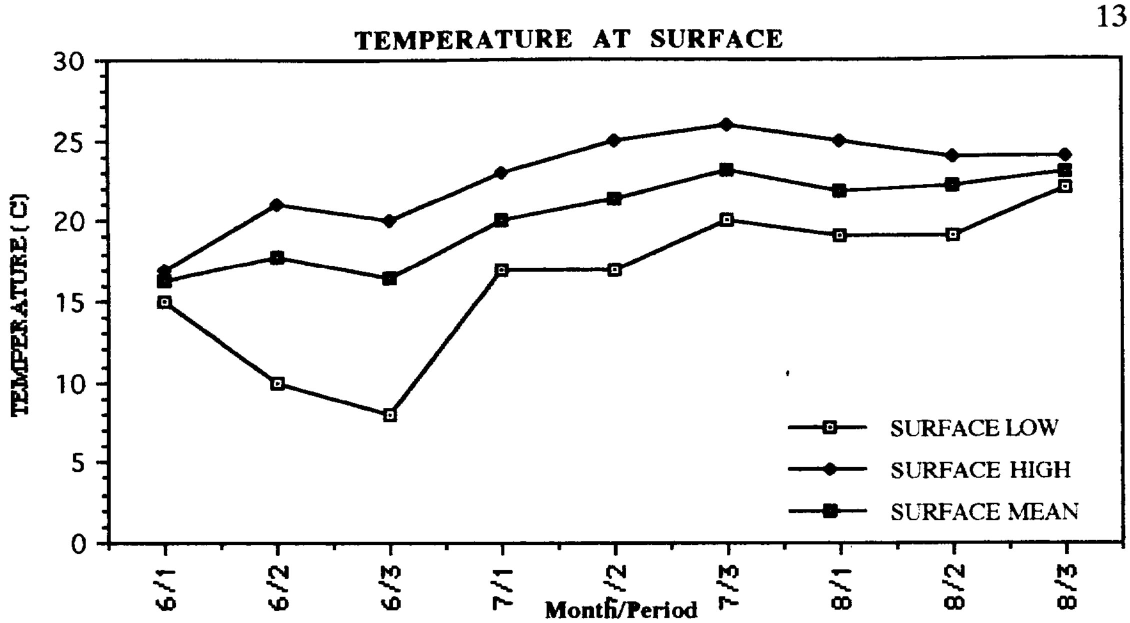
Available temperature data were plotted for yearly comparison from 1983 to 1992 according to three monthly periods in each of the months of June, July, and August. The months were partitioned into thirds as follows: period 1 for days 1-10, period 2 for days 11-20, and period 3 for days 21-30/31. Temperatures at the surface, 5m, and 10m depths were considered. Also, bottom temperatures were examined from samples taken at shallow depths (4-7m). Zeros on graphs represent periods in years when temperature profiles were unavailable because sampling did not take place. Although the available data are incomplete in a few cases, some anomalies in the general pattern may indicate significant events.

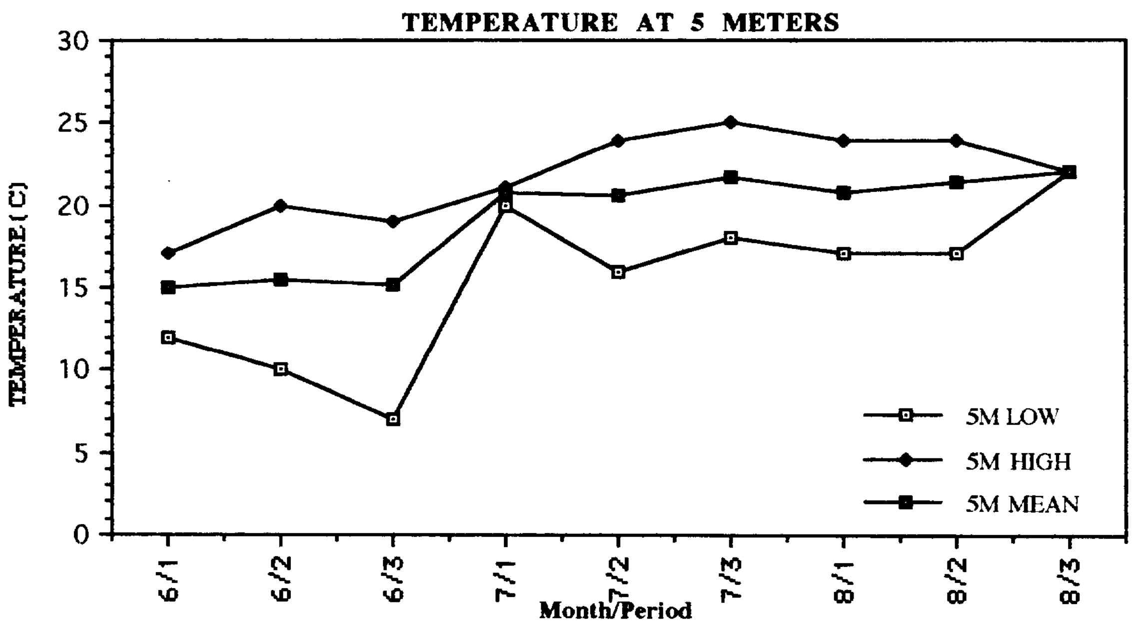
Overview

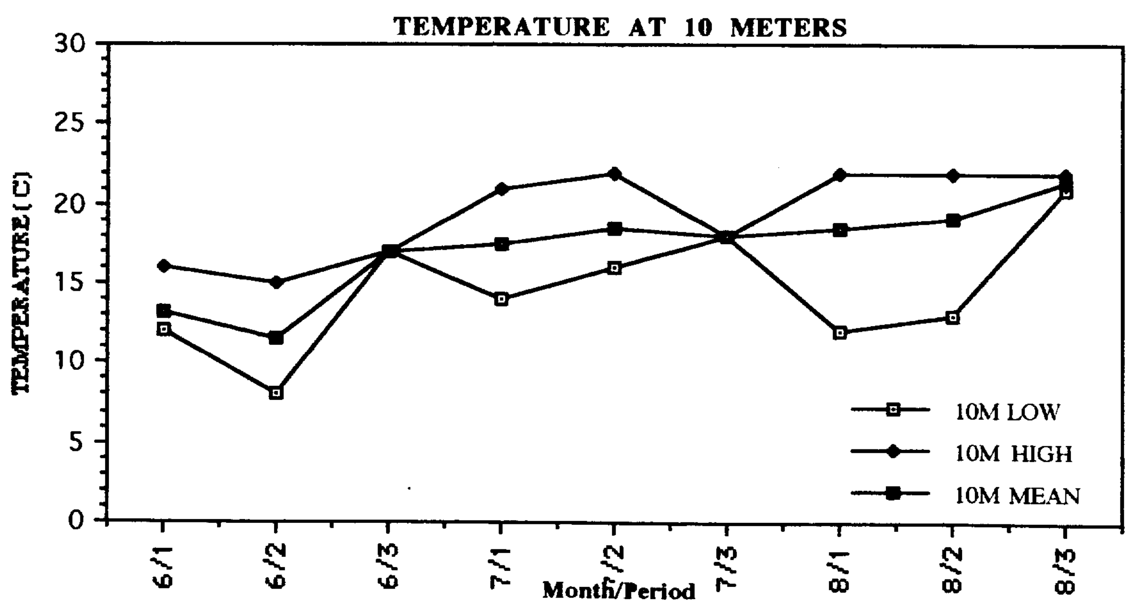
The expected temperature pattern in a temperate lake during the summer might consist of a steady, near-linear increase from June to July with leveling off in August. With some exceptions, the data analyzed here fit this pattern. Lows, highs, and means were examined for each depth (Table 1). Surface and 5m temperatures suggest a general pattern of increase throughout June and July, followed by a leveling off and in some cases a slight decrease in August (Figure 2). Temperatures from 10m depths are more variable, and do not show any definite pattern of increase or decrease. In Figure 3, each point on the scatter plot represents the average temperature

Table 1. Lows, highs, and average (mean) temperatures for three periods by month for June, July, and August in site K.

Month	Period	Surface			5 Meters			10 Meters		
		L	H	M	L	H	M	L	H	M
June	1-10	15.0	17.0	16.2	12.0	17.0	15.0	12.0	16.0	13.2
	11-20	10.0	21.0	17.7	10.0	20.0	15.5	8.0	15.0	11.5
	21-30	8.0	20.0	16.5	7.0	9.0	15.2	17.0	17.0	17.0
July	1-10	17.0	23.0	20.0	20.0	21.0	20.7	14.0	21.0	17.2
	11-20	17.0	25.0	21.4	16.0	24.0	20.6	16.0	22.0	18.5
	21-31	20.0	26.0	23.1	18.0	25.0	21.7	18.0	18.0	18.0
August	1-10	19.0	25.0	21.8	17.0	24.0	20.8	12.0	22.0	18.5
	11-20	19.0	24.0	22.1	17.0	24.0	21.4	13.0	22.0	19.2
	21-31	22.0	24.0	23.0	22.0	22.0	22.0	21.0	22.0	21.5


TEMPERATURE AT SURFACE
TEMPERATURE (C)
30
25
20
15
10
5
0
6/1
6/2
6/3
7/1
7/2
7/3
8/1
8/2
8/3
Month/Period
SURFACE LOW
SURFACE HIGH
SURFACE MEAN


TEMPERATURE AT 5 METERS
TEMPERATURE (C)
30
25
20
15
10
5
0
6/1
6/2
6/3
7/1
7/2
7/3
8/1
8/2
8/3
Month/Period
5M LOW
5M HIGH
5M MEAN


TEMPERATURE AT 10 METERS
TEMPERATURE (C)
30
25
20
15
10
5
0
6/1
6/2
6/3
7/1
7/2
7/3
8/1
8/2
8/3
Month/Period
10M LOW
10M HIGH
10M MEAN

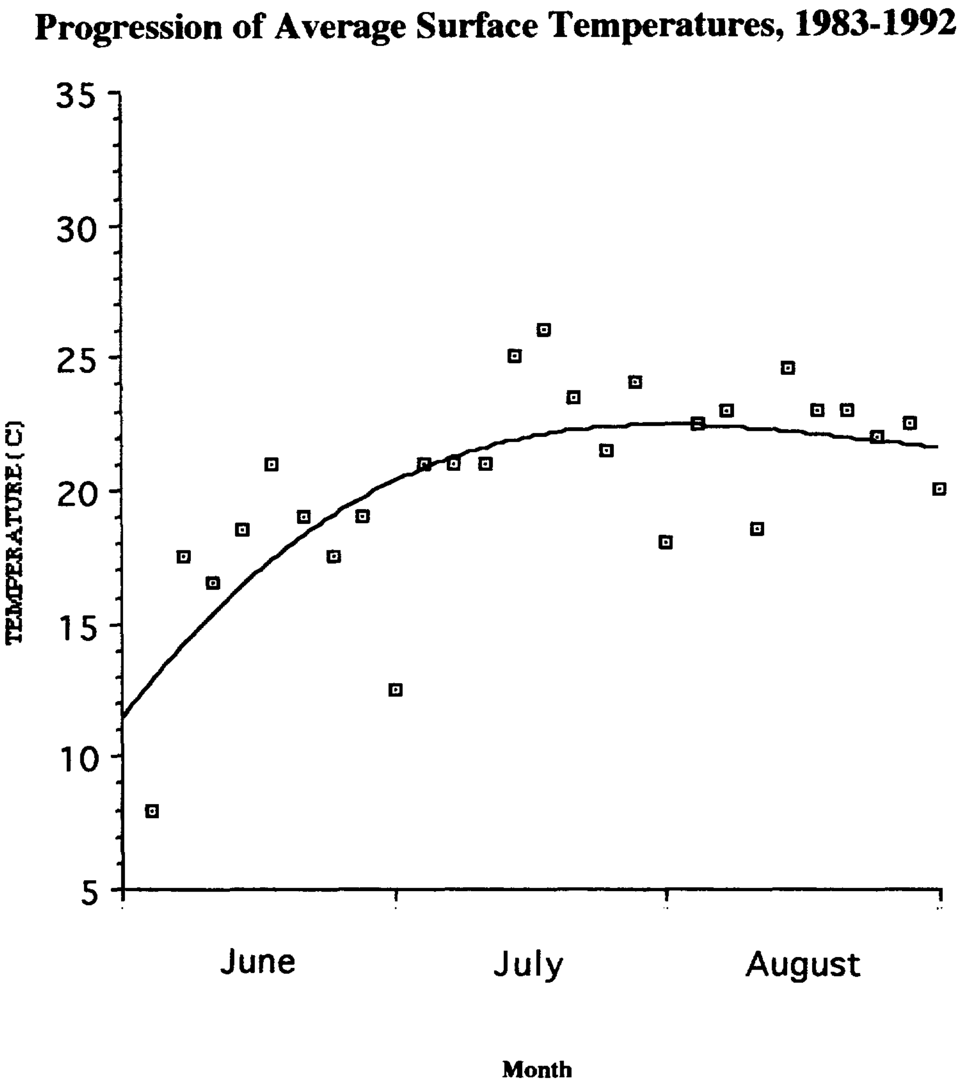
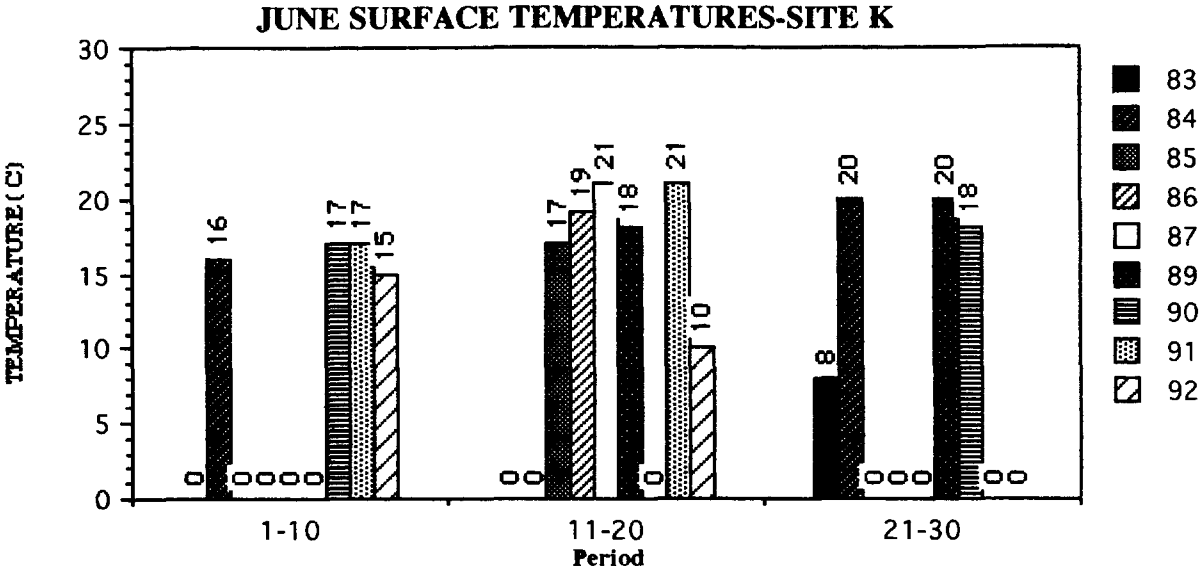


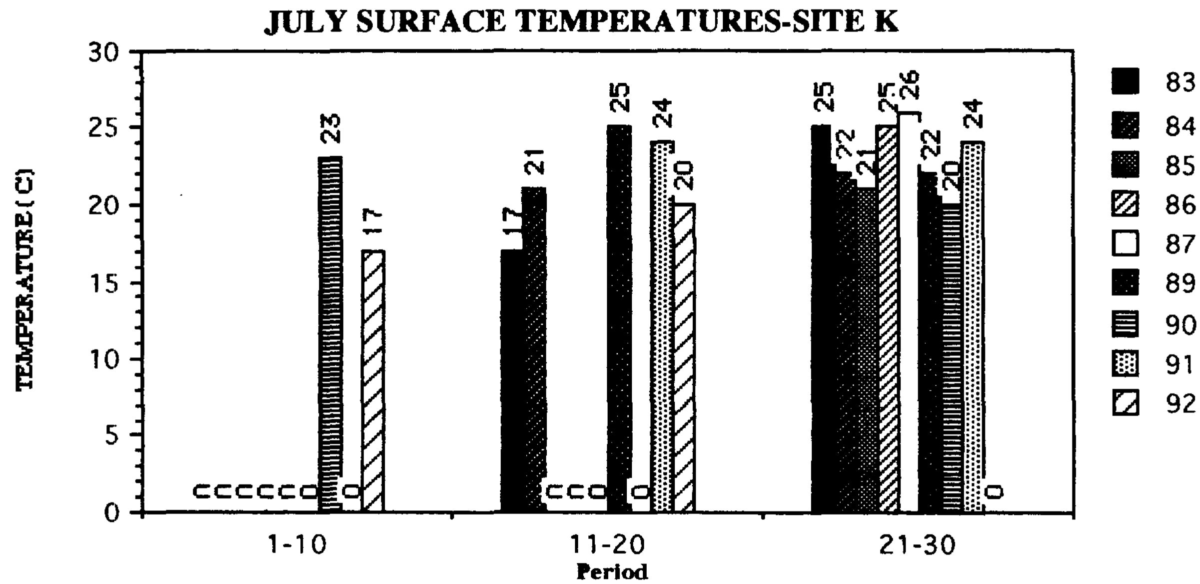
Figure 3. Scatter plot of average monthly temperatures for all years, 1983-1992.

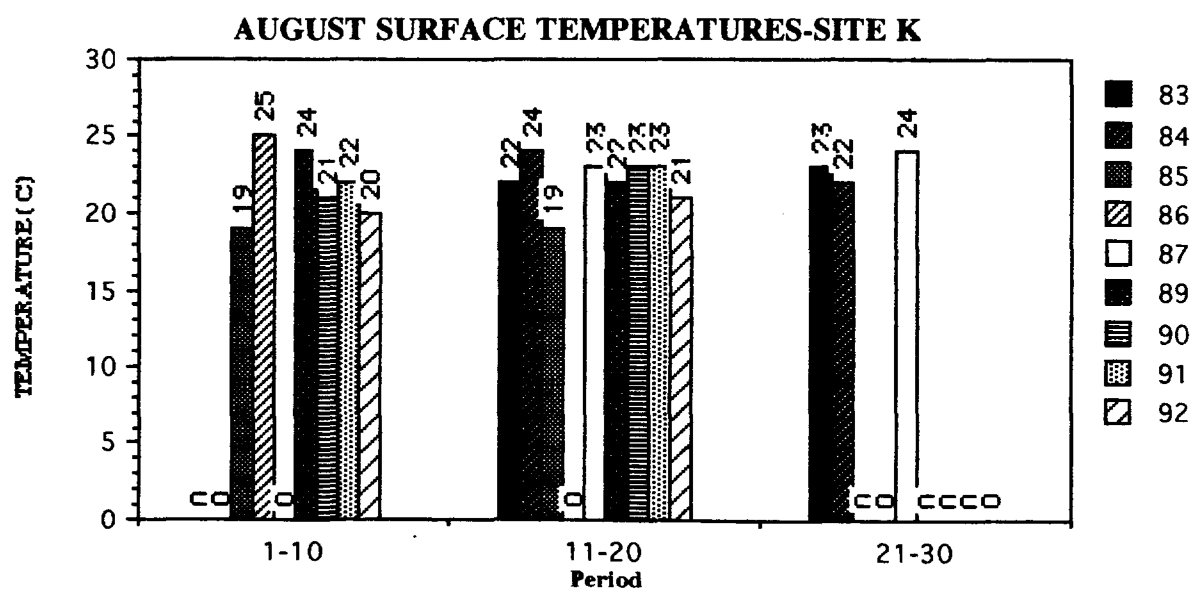
for one month of one year (i.e. there are 27 points, each representing one of the 27 months of the study). Overall, temperatures were higher in July than in June, but an increase did not continue into August. Furthermore, linear increases in June and July were not found in any year. Instead, each year exhibited some anomaly, that is, an incident of extreme temperature, negating any linear relationship. Examples include surface temperatures of 10°C in June, 1992 (Figure 4a), and 8°C in June, 1983 (Figure 4a), as well as a surface temperature of 26°C in July, 1987 (Figure 4b).

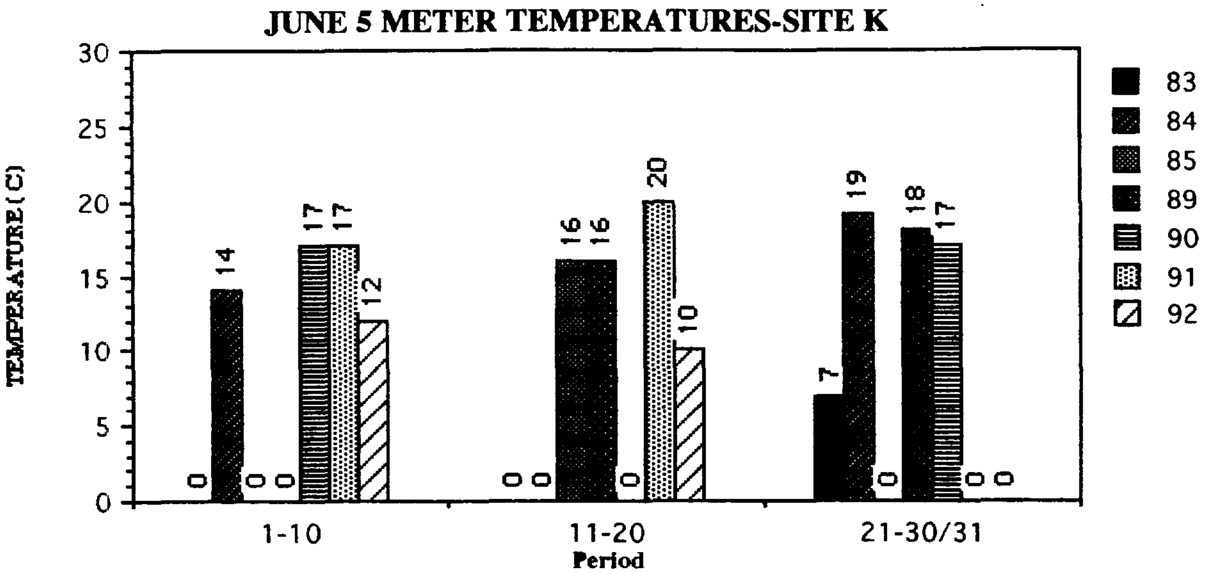
Cool Years

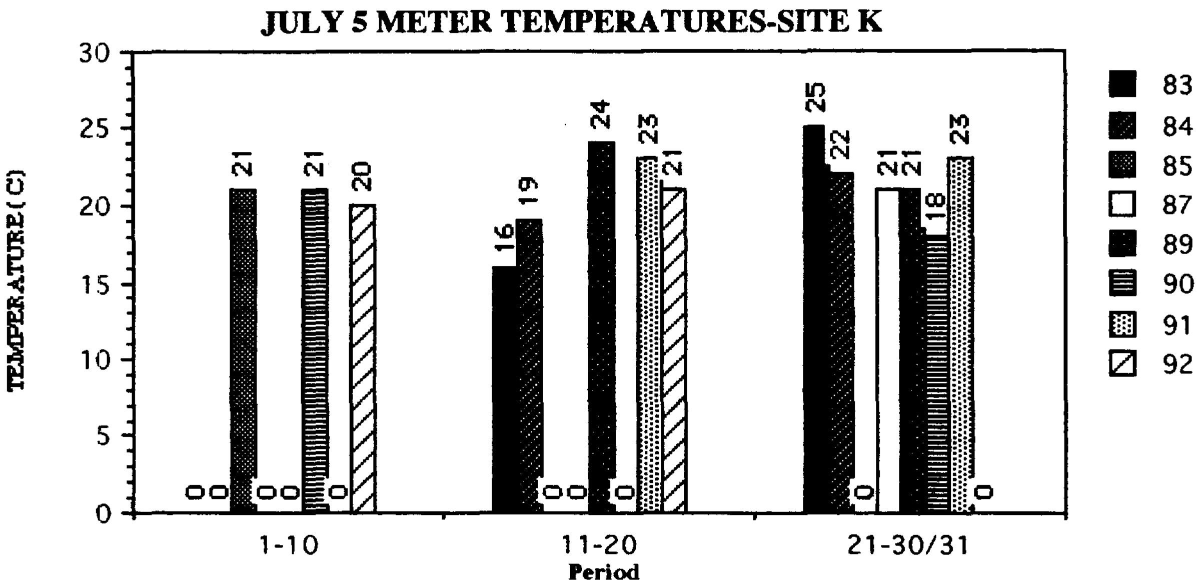
The 1992 year was generally cooler throughout all the summer months (Figures 5-7). Average surface temperature during this year was 15.5°C (Table 2). This cool trend was especially evident in mid-June, when surface, 5m, and shallow bottom temperatures ranged only from 8-10°C (Figures 4a, 5a, 7a). This contrasts with the 16-21°C range recorded in most other years. July and August temperatures for 1992 also reflect this cool pattern, displaying a range of 14-21°C, as opposed to 16-26°C in other years. Another example of a cool year was 1985. Although temperatures during this year were not drastically lower, the temperature at 10m was especially low, with recordings of 12°C and 13°C, as compared to the 19-22°C range for other years (Figure 6c). Average temperature during this year was 17°C.


JUNE SURFACE TEMPERATURES-SITE K
TEMPERATURE (C)
Period
1-10
11-20
21-30
83
84
85
86
87
89
90
91
92


JULY SURFACE TEMPERATURES-SITE K
TEMPERATURE (C)
Period
1-10
11-20
21-30
83
84
85
86
87
89
90
91
92


AUGUST SURFACE TEMPERATURES-SITE K
TEMPERATURE (C)
Period
1-10
11-20
21-30
83
84
85
86
87
89
90
91
92


JUNE 5 METER TEMPERATURES-SITE K
TEMPERATURE (C)
30
25
20
15
10
5
0
0 14 0 0 17 17 12
0 0 16 16 0 20 10
7 19 0 18 17 0 0
1-10
11-20
21-30/31
Period
83
84
85
89
90
91
92


JULY 5 METER TEMPERATURES-SITE K
TEMPERATURE (C)
30
25
20
15
10
5
0
0 0 21 0 0 21 0 20
16 19 0 0 24 0 23 21
25 22 0 21 21 18 23 0
1-10
11-20
21-30/31
Period
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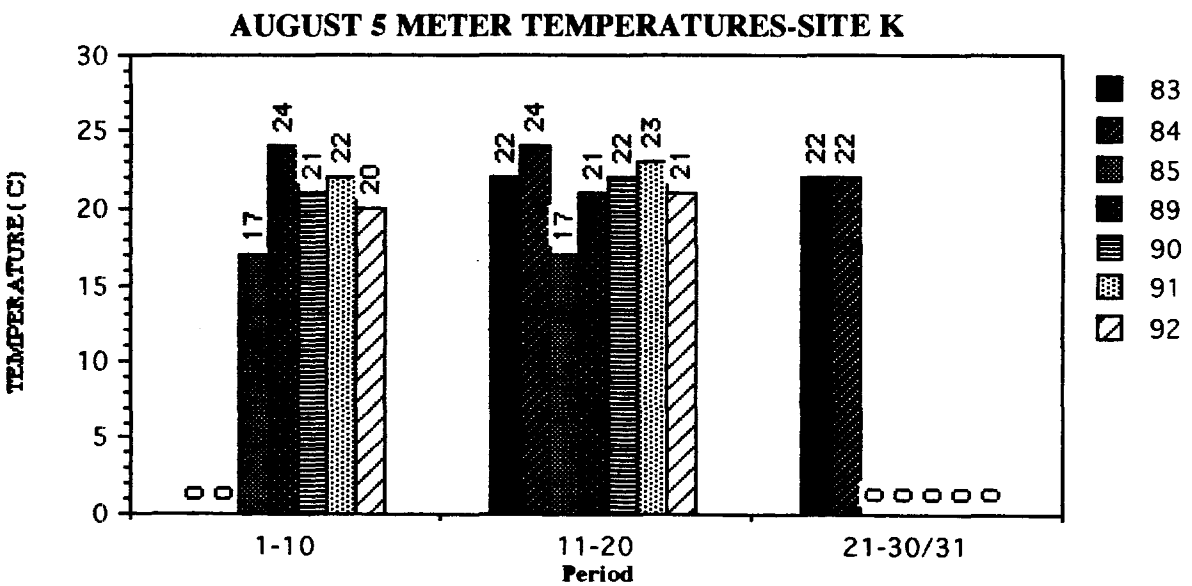
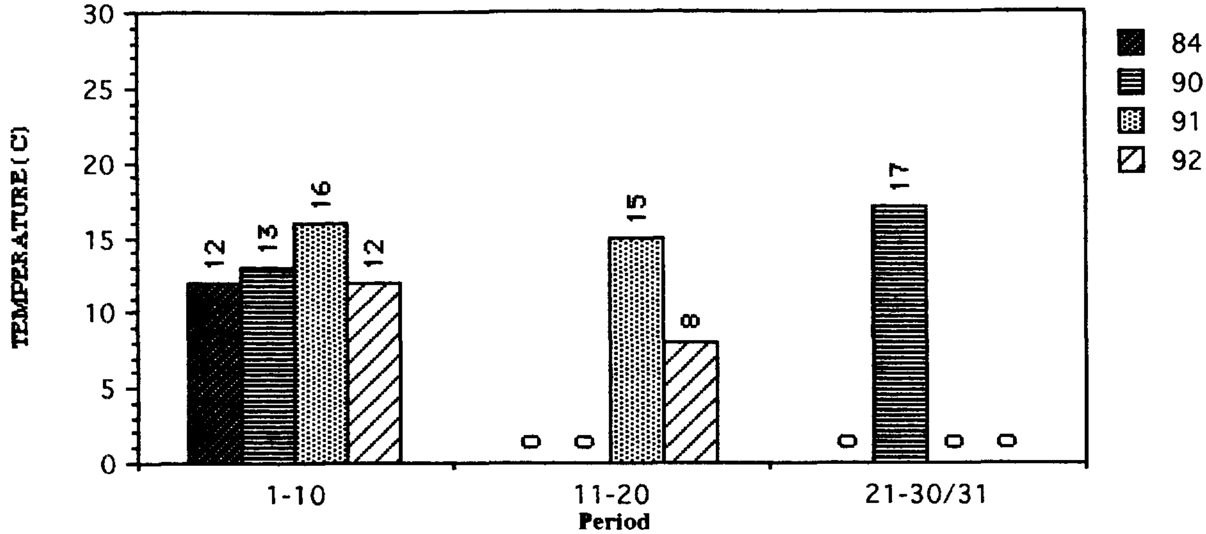
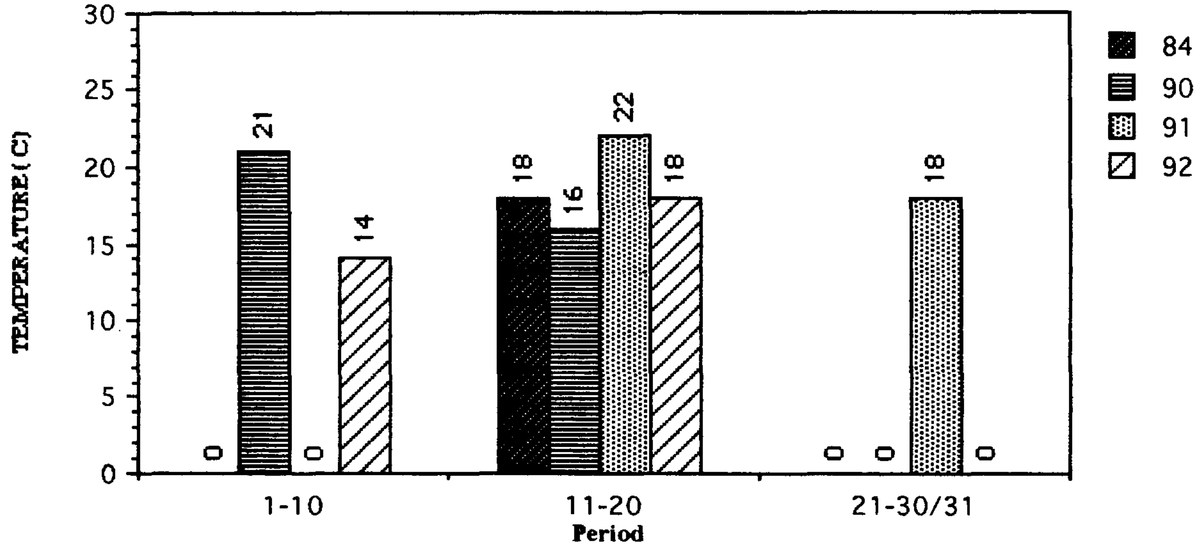
84
85
87
89
90
91
92


AUGUST 5 METER TEMPERATURES-SITE K
TEMPERATURE (C)
30
25
20
15
10
5
0
0 0 17 24 21 22 20
22 24 17 21 22 23 21
22 22 0 0 0 0 0
1-10
11-20
21-30/31
Period
83
84
85
89
90
91
92

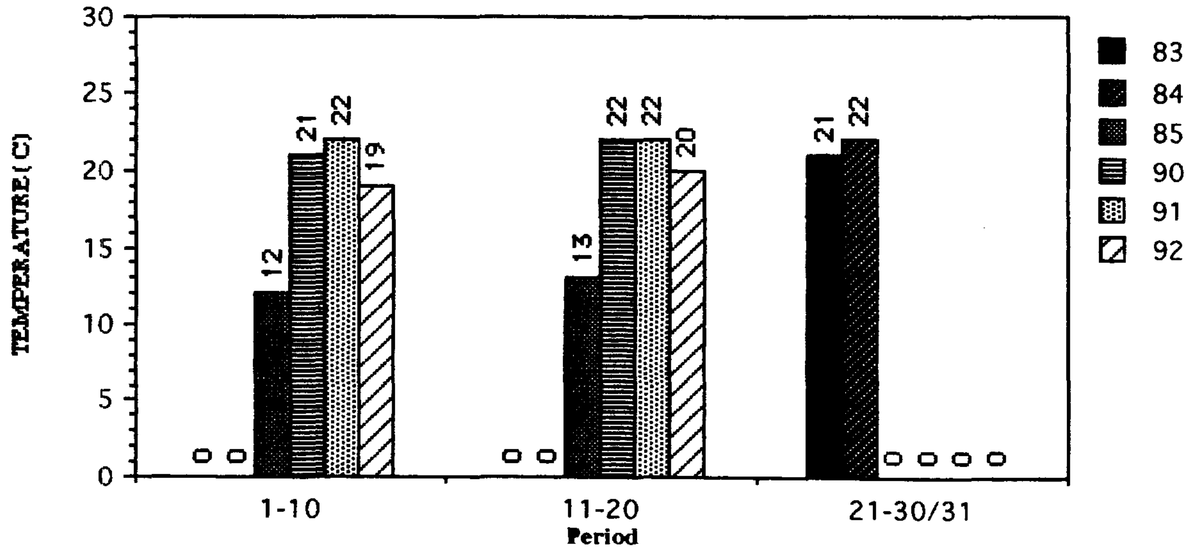
JUNE 10 METER TEMPERATURES-SITE K



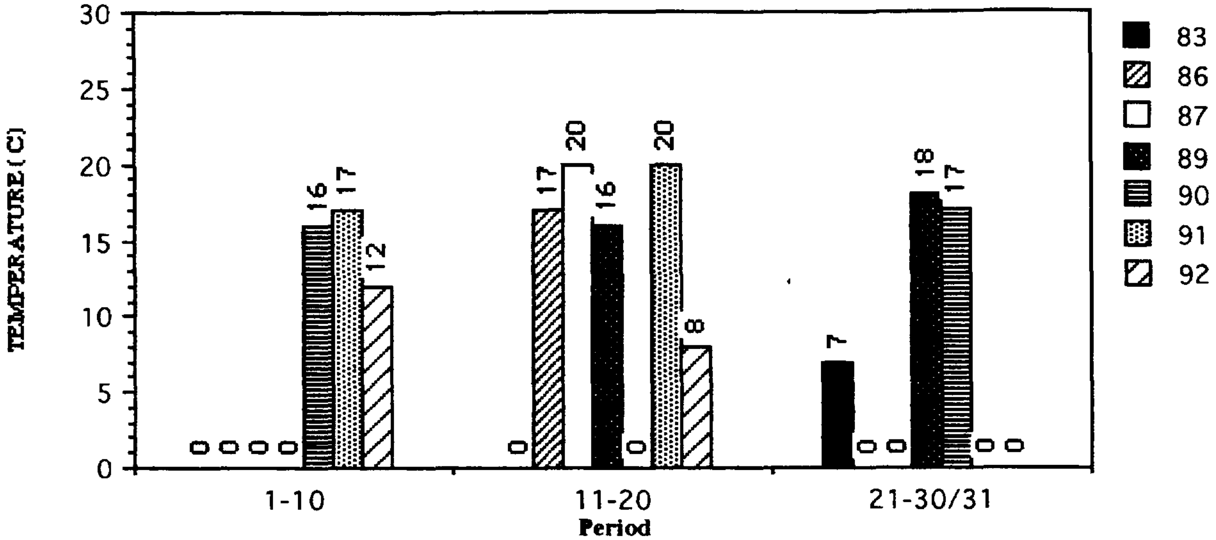
JULY 10 METER TEMPERATURES-SITE K



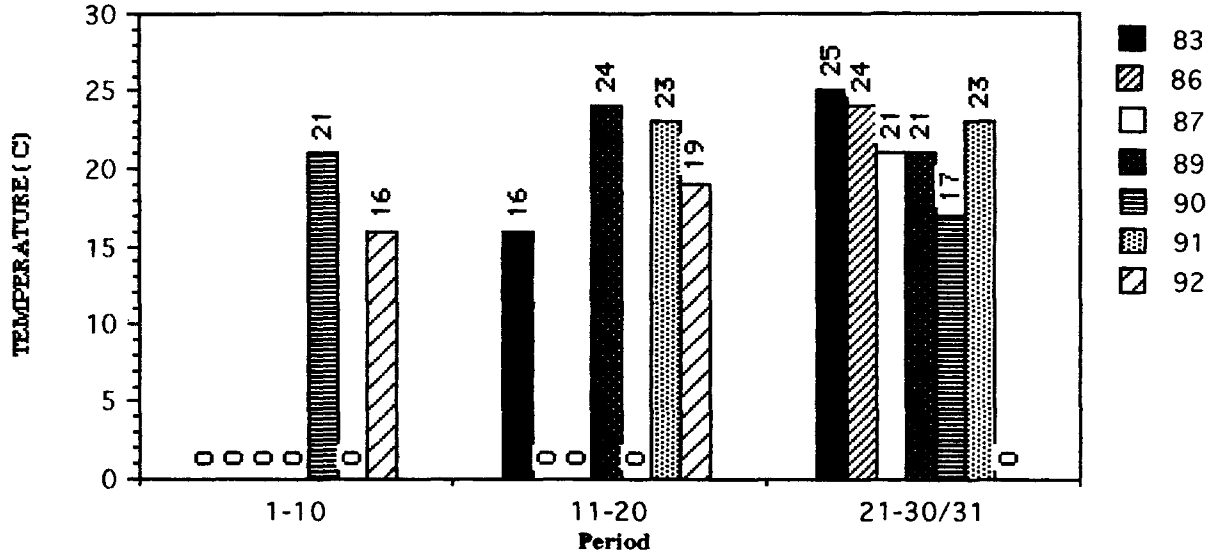
AUGUST 10 METER TEMPERATURES-SITE K



JUNE BOTTOM TEMPS-SHALLOW (4-7m)



JULY BOTTOM TEMPS-SHALLOW (4-7m)



AUGUST BOTTOM TEMPS-SHALLOW (4-7m)

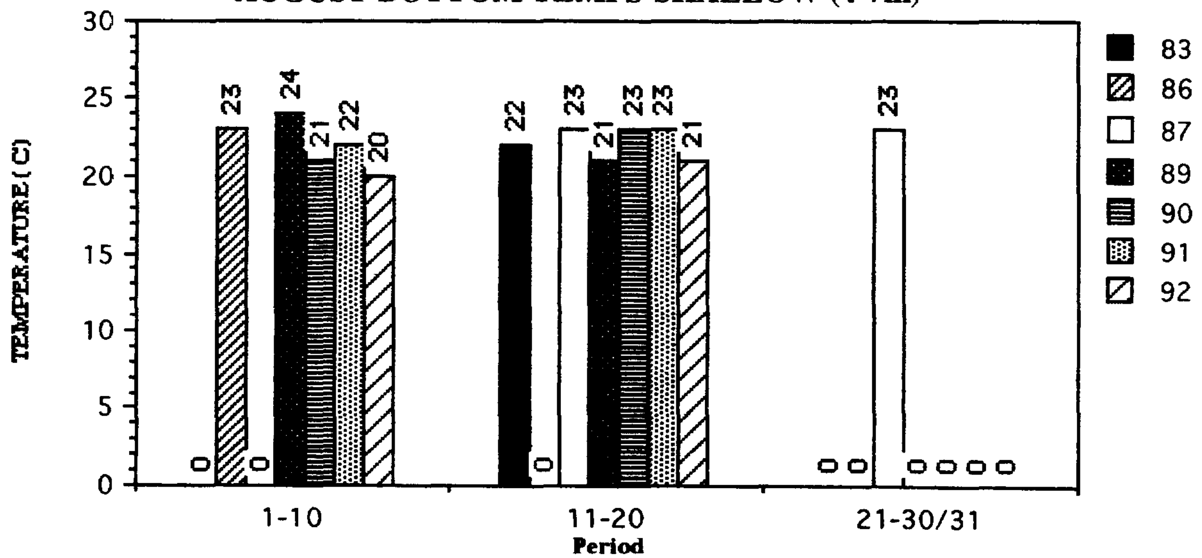


Table 2. Seasonal average temperatures for each year, 1983-1992.

Year	Avg. Temp (C)	Year	Avg. Temp (C)
1983	18.5	1989	21.0
1984	19.5	1990	18.5
1985	17.0	1991	19.5
1986	22.0	1992	15.5
1987	22.5		

The coldest temperature recorded for any date occurred in late June, 1983. Surface temperature on this sampling day reached only 8°C (Figure 4a), and 5m temperature only 7°C (Figure 5a).

Warm years

Examples of warmer years include 1986 and 1987. In 1986, surface temperatures ranged from 19-25°C, and bottom temperatures from 17-24°C (Figures 4 and 7). Little variation existed in the temperatures for this year. Average temperature in 1986 was 22°C. The 1987 season was similar, in that an average of 22.5°C was obtained, and a range of 20-26°C existed for the entire summer. Unlike many other years, particularly during June, 1987 never exhibited a recorded temperature below 20°C. In addition, the highest temperature ever recorded, at 26°C, was during July of 1987 (Figure 4b).

Thermocline

Evidence of thermocline areas were often subtle and difficult to define (Figures 8-11). The expectation, as the summer progresses, would be for the thermocline to move deeper and deeper as atmospheric temperatures grow hotter to warm the surface waters. This is best illustrated by the composite profiles of 1983 (Figure 8). The thermocline in this year started at 1m in late June, and progressed to 4m by August. In other years, the thermocline

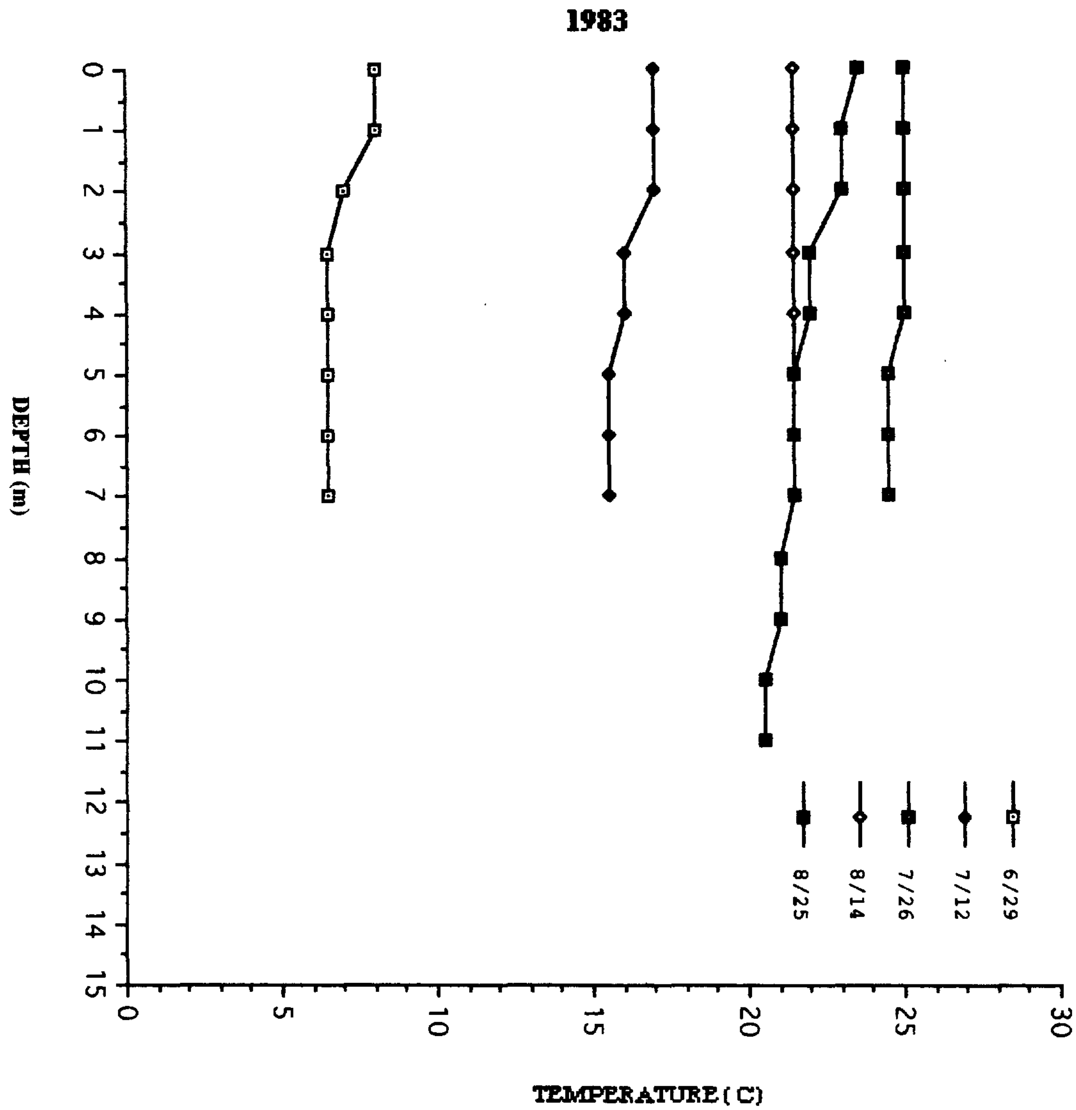


Figure 8. Composite temperature profiles for 1983.

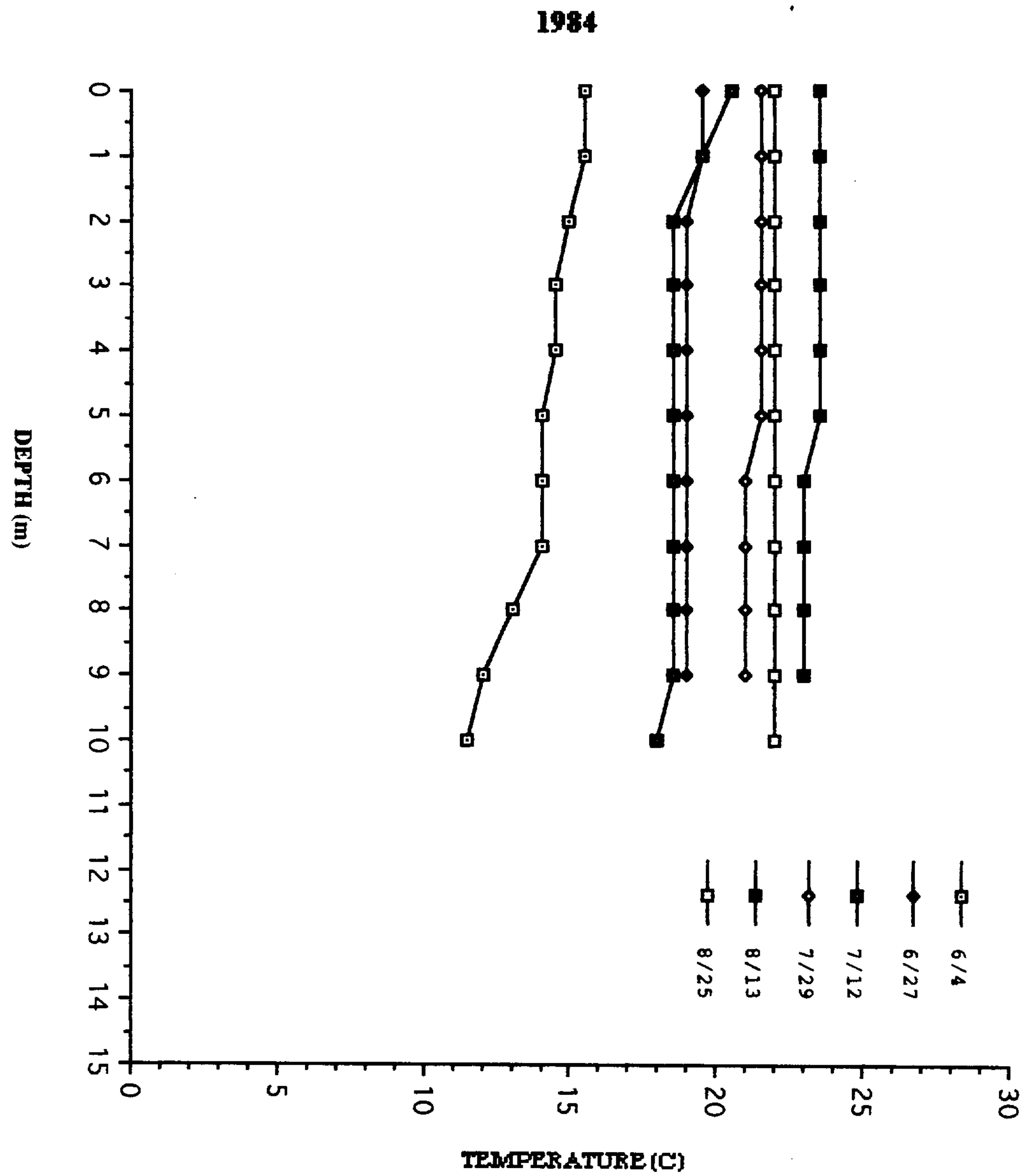


Figure 9. Composite temperature profiles for 1984.

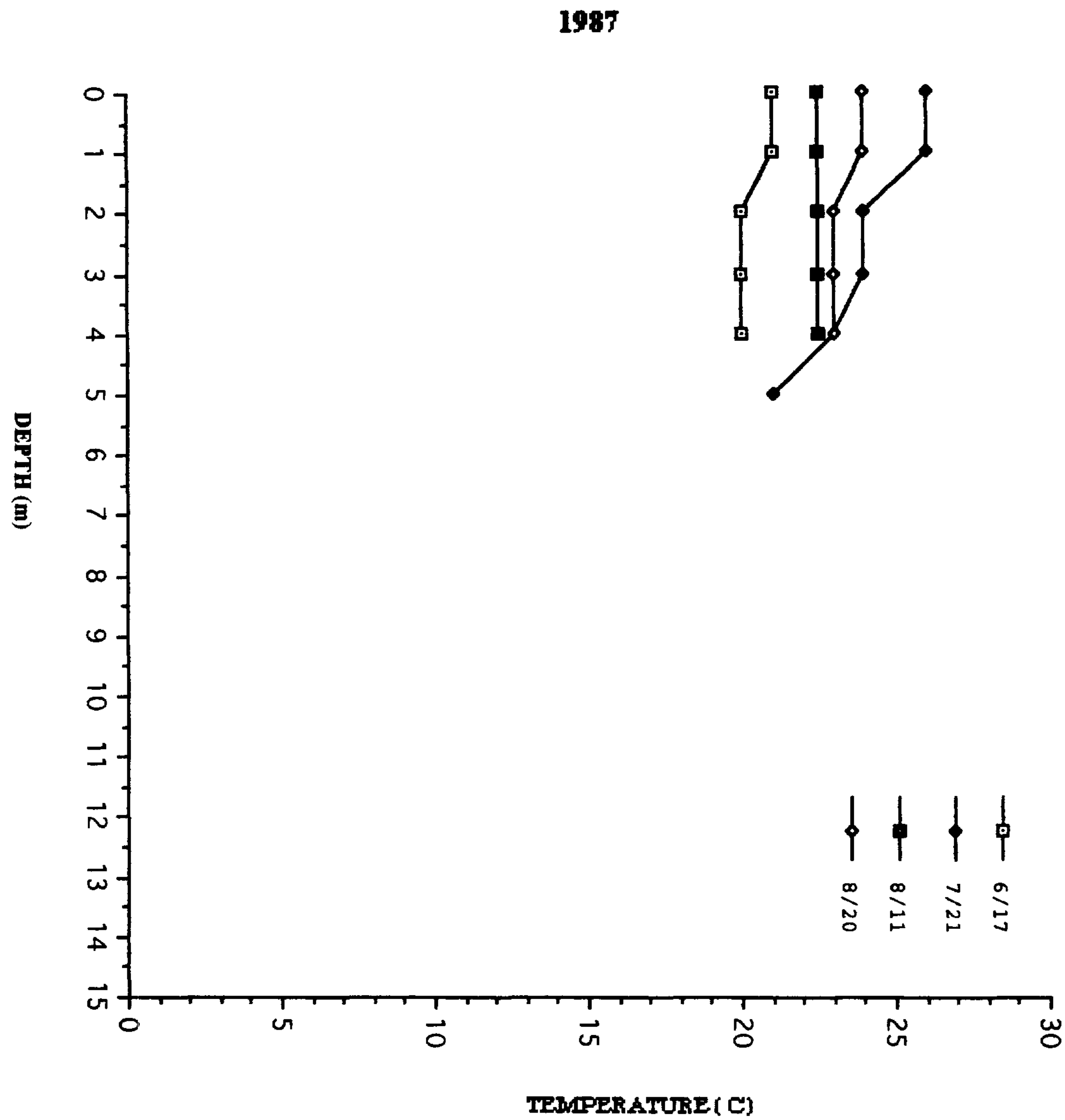


Figure 10. Composite temperature profiles for 1987.

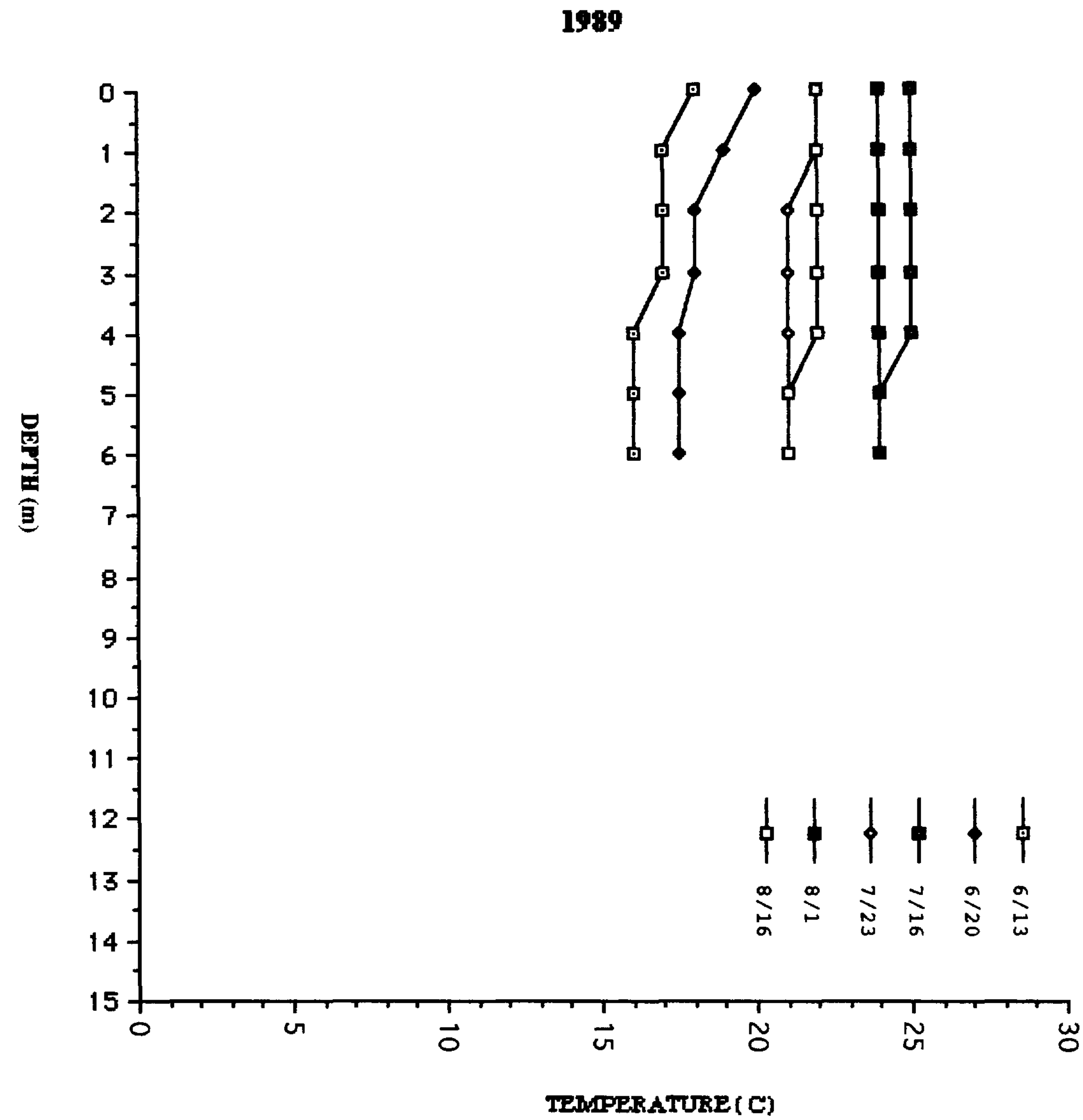


Figure 11. Composite temperature profiles for 1989.

cannot be defined precisely, however, temperature changes of 1°C or more generally began to occur more than 1m below the water's surface. Profiles which appear as straight lines occur in 1984, 1987, and 1989 (Figures 9, 10, 11), and indicate loss or alteration of the thermocline. Composites for all years can be found in the appendix.

Summary

The expected trend of increasing temperatures from June to August was found with some modification in the data for 1983-1992. Temperatures tended to increase in June and July, and level off in August. Anomalies did exist, however, to move the data away from this overall pattern.

Cool seasons were observed in the years 1985 and 1992. Both showed averages that were slightly below the recorded temperatures for other years. June of 1985 was particularly cool, while 1992 remained cool throughout the summer months.

Warmer seasons were observed in the data from 1986 and 1987. Both years provided temperatures that, except in June of 1986, were always in excess of 20°C. Average temperatures for these years were near to 22°C, and the highest temperature in the data at 26°C was found in late July of 1987.

Indications of global warming might include a yearly increase in temperature averages, warmer temperatures early in the season, and the complete and consistent disappearance of the thermocline. The data presented here show no evidence of these events. In fact, if the effects of the data for the years 1985 and 1992 are not considered, little year-to-year variation can be seen with regard to any significant warming or cooling.

DISCUSSION

Overview

Given the considerable size of Lake Michigan, and the unpredictability of the weather surrounding it, variation in temperatures are expected. Anomalies in data such as isolated occurrences of high or low temperatures are accountable for by factors such as weather events, internal seiches, and upwellings, or some combination of these factors. Aside from some isolated and explainable events, temperatures from the summer season throughout the decade showed relatively minor variations. For the most part, temperatures began a general increase at the onset of spring, a trend which continued until the month of August, when variation occurred in some cases. The fact that August temperatures in some cases increased, while in others decreased or remained the same, is attributable to weather variability.

Cool years

The years 1985 and 1992 were considered cool years due to their slightly lower temperature readings and averages. The 1992 year was generally cooler throughout the summer, probably because of the very rainy and unseasonably cool weather throughout the entire season. In 1985, however, temperatures from the months of June and July were consistent with other years, while only in August were temperatures considerably lower. This suggests a cold or stormy month, which may have resulted in seiches or upwellings, causing water temperatures to decline. The coldest temperature recorded, from 1983, was also likely caused by a severe weather event in the last week of June, causing strong mixing or a temperature seiche. Weather events such as these, while in most cases not severe enough to affect the lake as a whole, are significant to the surface and shallow water areas, and the biota associated with them. For example, a cold spell can temporarily drive particular species of fishes into other areas. A prolonged cold period could potentially cause the fish to become somewhat dormant, and possibly even halt growth for a time. Rain, the cause of most low temperatures, may potentially be acid rain, containing a variety of pollutants, in which case the chemical composition of the water may also be impacted.

Warm years

The warm years of 1986 and 1987 could be attributed to warm atmospheric temperatures, and significant wind action to mix the warmer water into lower depths. However, sampling in these two years occurred only from late June to August, thereby possibly raising the averages by taking away the cooling effect of earlier June temperatures in favor of the typically hotter July and August months. In addition, the bottom profile depth of these two years was only at 4m. This shallow depth would be expected to exhibit warmer temperatures, because solar radiation would penetrate the water layers more effectively and with more intensity. Like extreme cold, hot temperatures may also cause the biota to retreat to other, more comfortable areas. Warmer water also has a lower capacity for holding oxygen, yet at the same time, fish in warmer water exhibit a higher rate of metabolism, causing them to require more oxygen. In this apparent "no-win" situation, a fish will likely move to other areas, or acclimate by becoming inactive.

Thermocline

The pattern of progressive increasing temperatures is consistent with the cycle of a dimictic lake. After spring overturn, the lake slowly becomes stratified, displaying a thermocline, a feature which generally remains throughout the summer. In a lake the size of Lake Michigan, the true thermocline would more easily be found in the deeper, offshore waters, which are less affected by weather events. Nevertheless, gradual decreases in temperature below 1m support the epilimnion-metalimnion-hypolimnion pattern. Different species of fish, phytoplankton, and zooplankton can be found consistently in each of these areas. Straight line profiles appearing to have no thermocline may indicate one of two things. Either the area has undergone significant mixing by wind and weather action, causing isothermy, or the thermocline has been forced down by high atmospheric temperatures and solar radiation, and is simply not detected in the sample locations at 15m depth or shallower. The latter explanation is more plausible in most cases, since straight line profiles were found only in the shallower profiles of 1984, 1987, and 1989 (Figures 9,10,11), while a deep profile for 1991 showed strong stratification and thermocline development (Figure 12). Temperature data from late autumn would likely show a gradual decrease in temperatures,

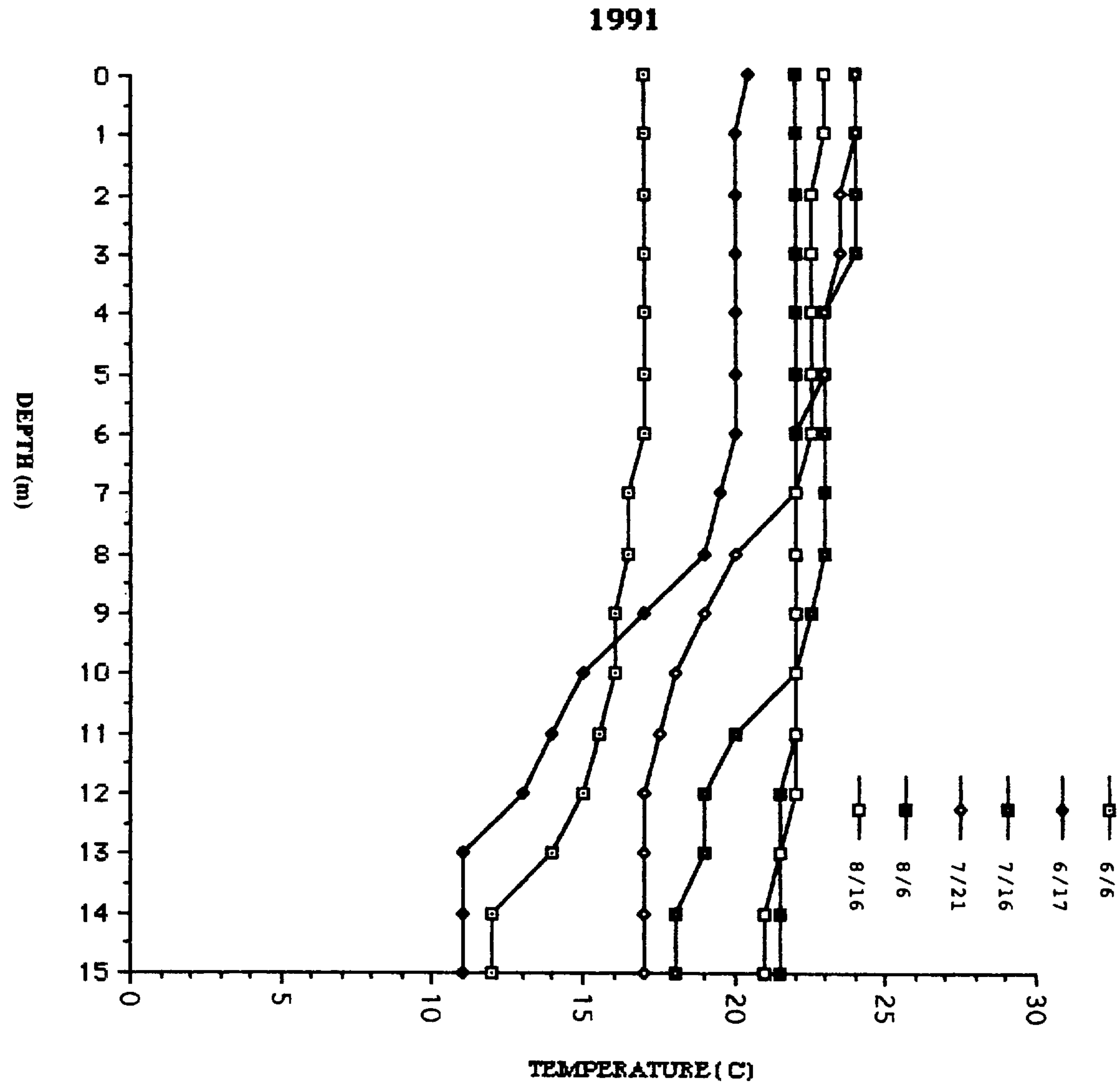


Figure 12. Composite temperature profiles for 1991.

a rising of the thermocline to shallower depths, including those studied here, and eventual loss of the thermocline as a result of autumnal overturn.

Summary

Incidences of extreme temperatures (high or low), which interfere with a general progression of increasing temperature from June to August are expected, and readily attributable to weather events in the nearshore area. Possibilities for significant variation in Lake Michigan exist due to the unpredictability of storm events in the midwest. Despite these anomalies, slight warming trends did exist, and, without the effects of the 1985 and 1992 cool years, little variation occurred.

Cool temperatures resulting from strong wind mixing and cold or significant rainfall can potentially harm the biota of a particular niche, by forcing it into other areas and possibly causing it to compete with other species.

Likewise, warmer temperatures, caused by intense solar radiation or drought, decrease the water's affinity for oxygen, while at the same time increasing an aquatic organism's need for it. Organisms such as fish and plankton may temporarily migrate to other areas, increasing the probability of interspecific competition, and subsequent decreasing health.

While current thermal patterns in Lake Michigan do not seem to reflect the growing concern over global climate warming, the future of the lake and others like it is uncertain. With the steady increase in global atmospheric temperatures due to the greenhouse effect, aquatic systems may change drastically, or they may sustain only minor changes. It is even possible that while some aquatic systems will have their temperatures raised, others may face a decrease in temperature or water level. Both will most likely be confronted with alteration of morphology and habitat, species succession, and possibly species migration or extinction. Careful monitoring of factors such as temperature, chemistry and water level must be maintained in order to assess the changes of the future.

CONCLUSIONS

Temperature data obtained in conjunction with Ball State University's Lake Michigan project were evaluated for trends and anomalies. Evaluation of temperature profiles from the surface to 4 to 15m depths, from 1983 to 1992 allows the following conclusions:

1. Lake Michigan shows small but progressive temperature increases from June through July and leveling off by August.
2. Isolated occurrences of extreme temperatures were most likely due to severe storm events and seiches, both of which are common to midwest area aquatic systems.
3. Thermoclines present in the summer profiles were consistent with the expected dimictic cycling pattern associated with Lake Michigan and other midwest lakes.
4. The greenhouse effect may be expected to influence Lake Michigan as well as other midwest aquatic systems, but as of 1992, no significant warming or cooling trends were detected.

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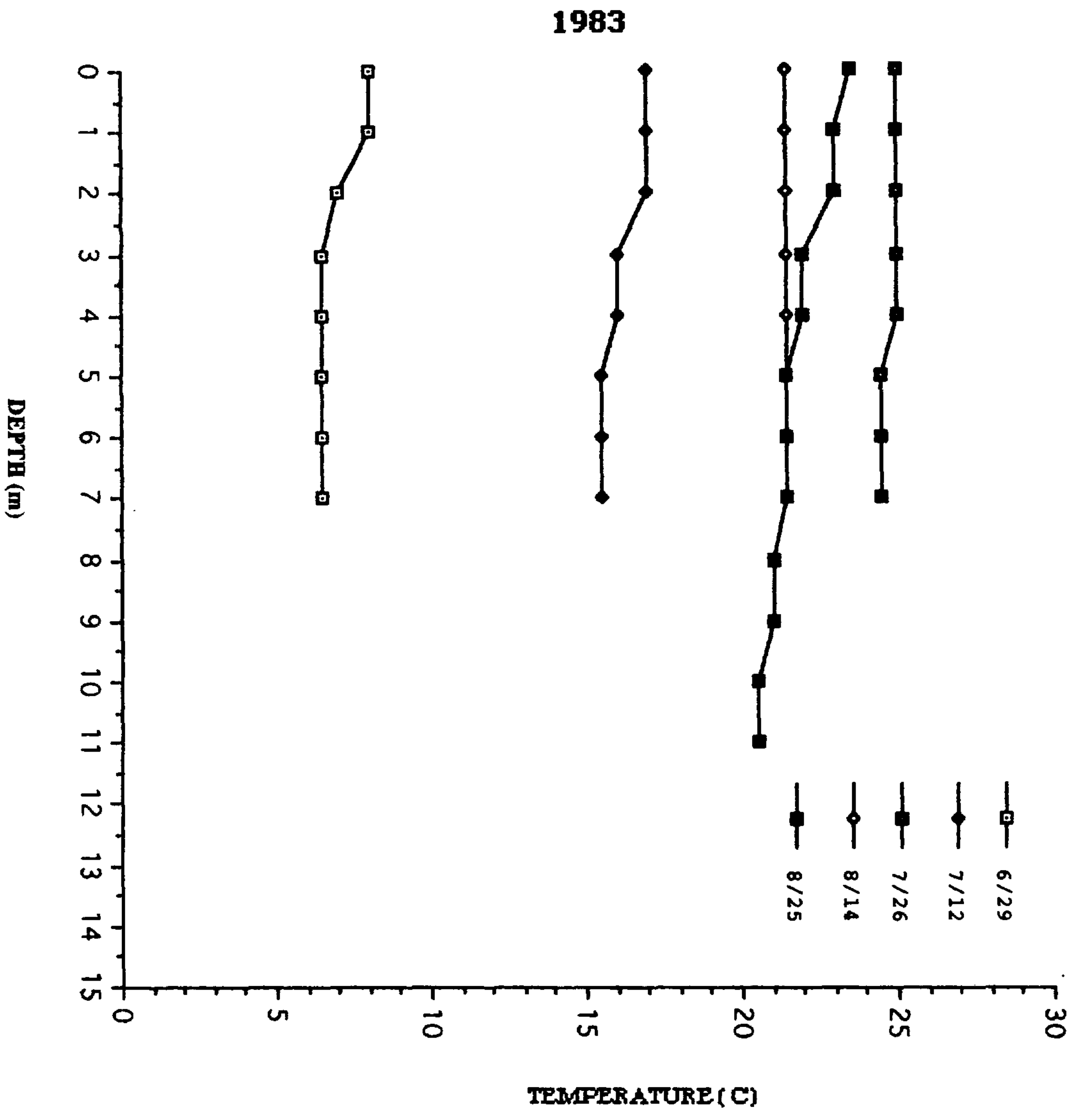
APPENDIX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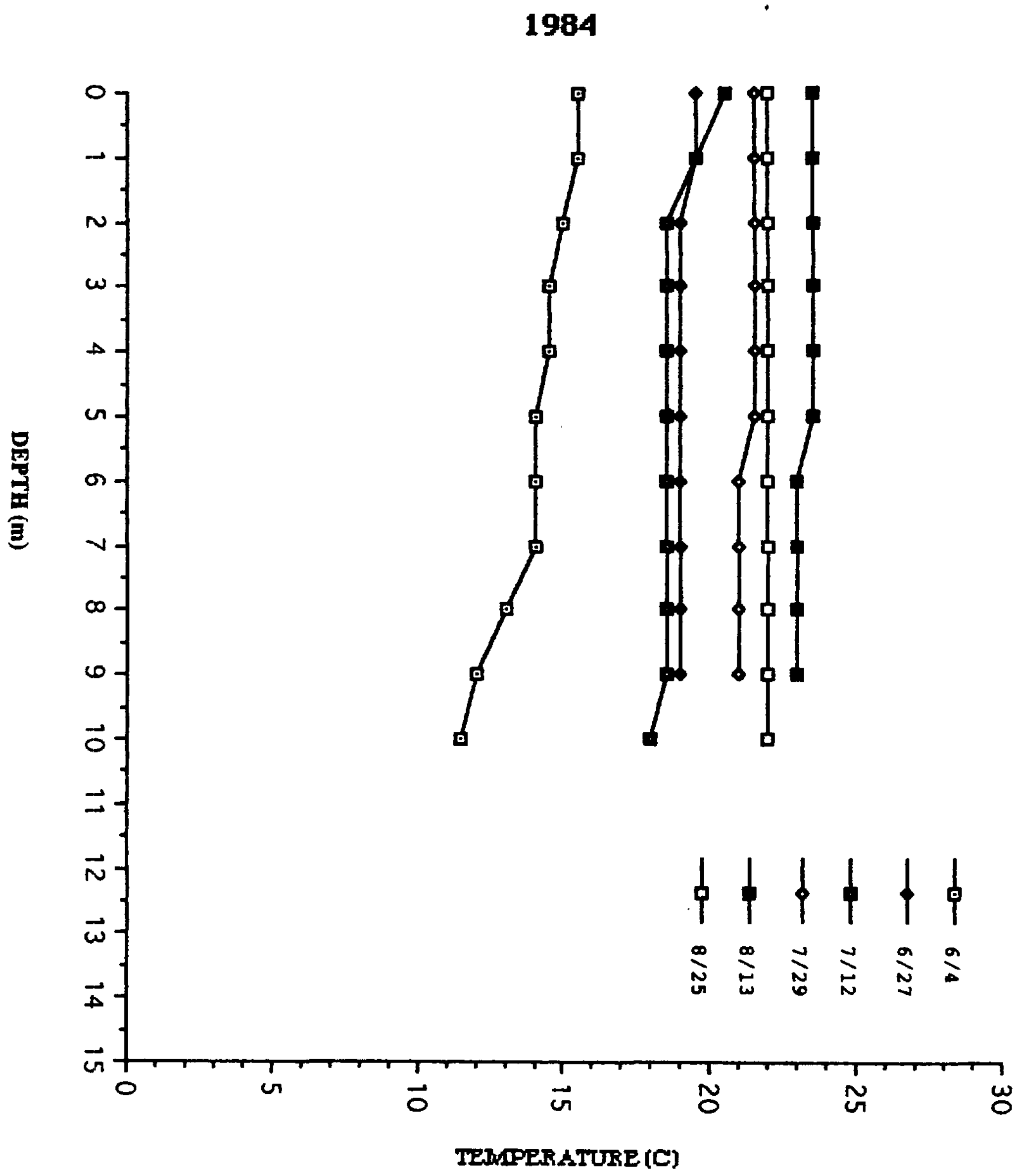
0 5 10 15 20 25 30
6/29
7/12
7/26
8/14
8/25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TEMPERATURE (C)
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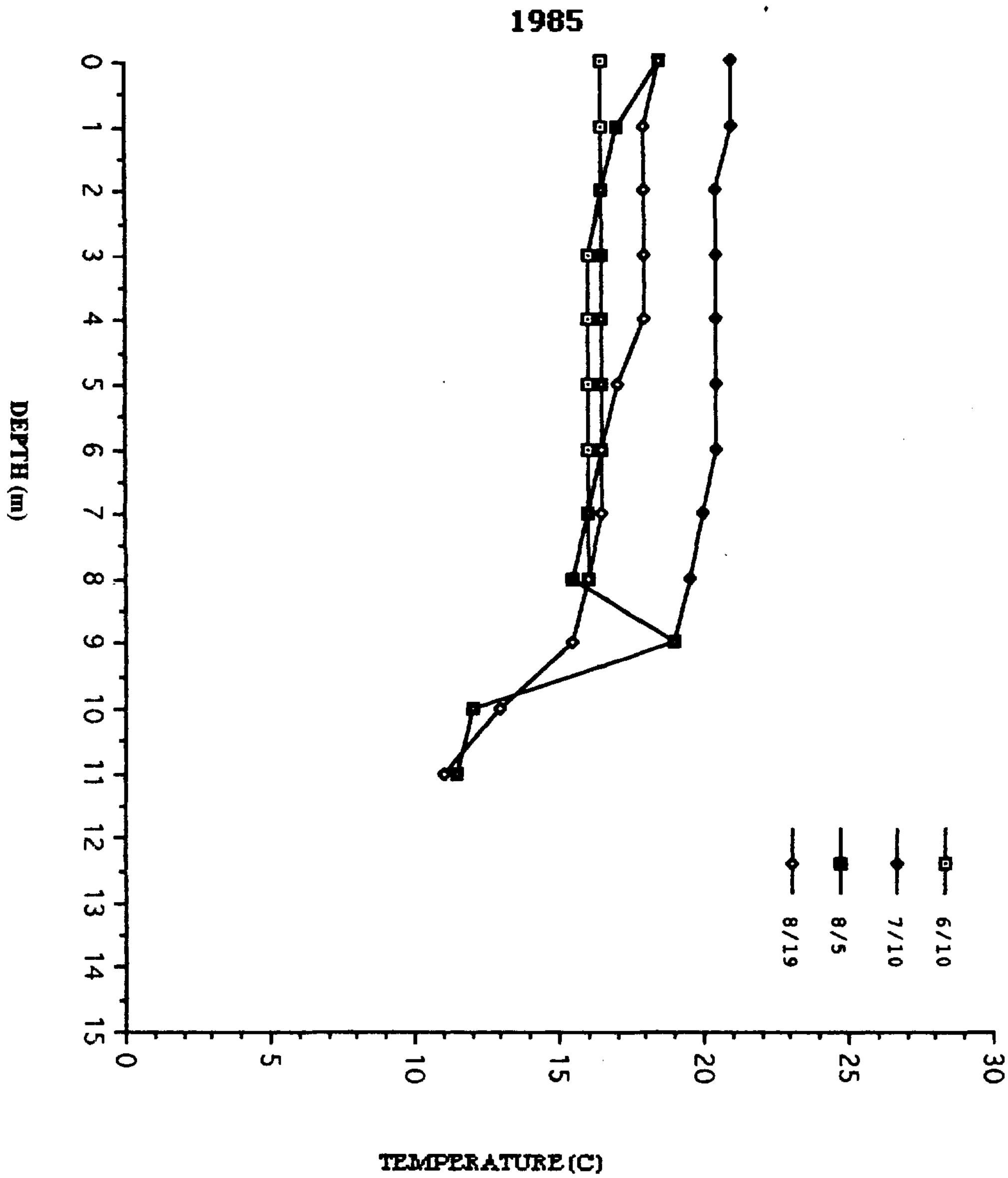
6/27
7/12
7/29
8/13
8/25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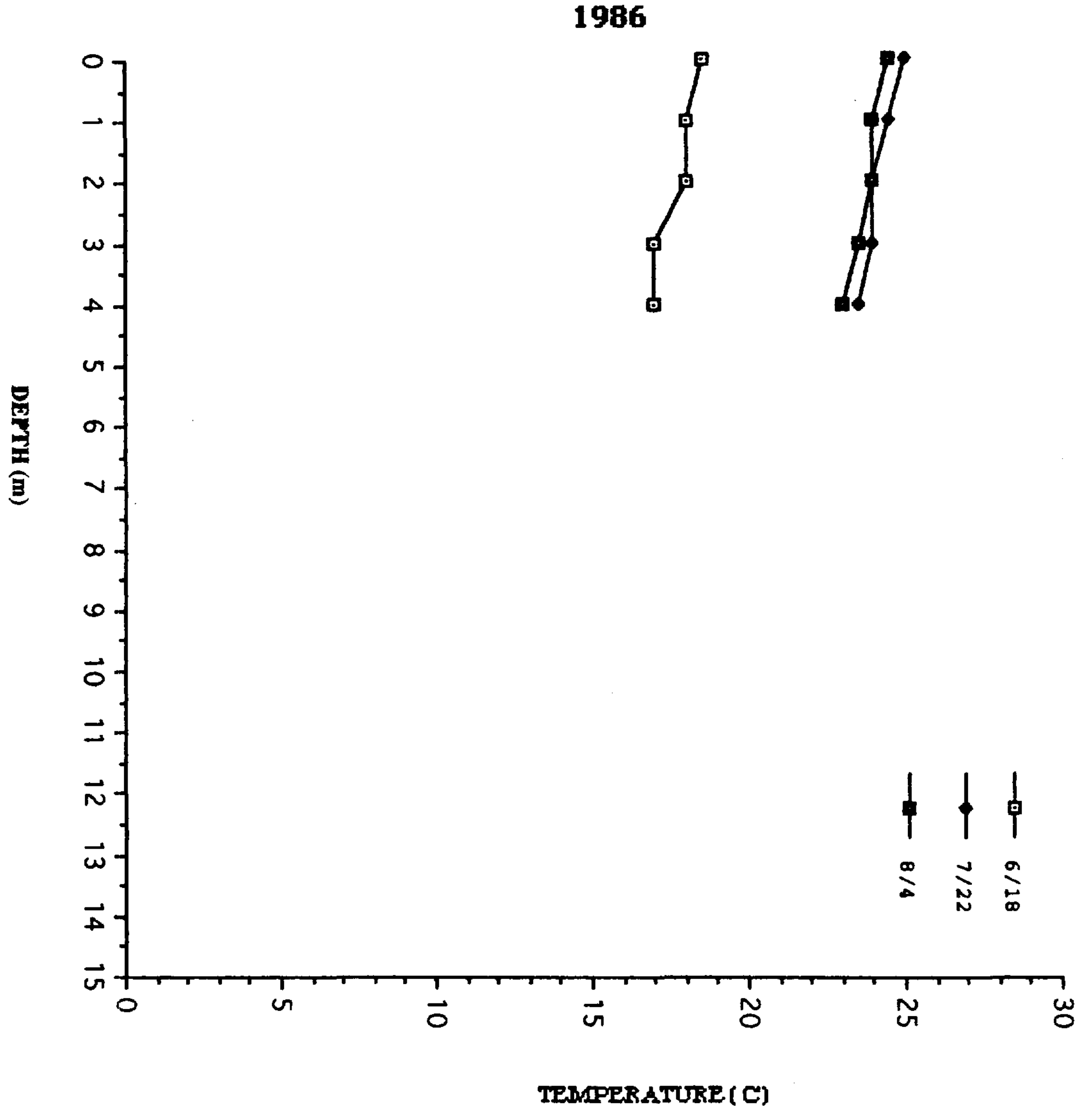
7/10
8/5
8/19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3
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6
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8
9
10
11
12
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14
15
TEMPERATURE (C)
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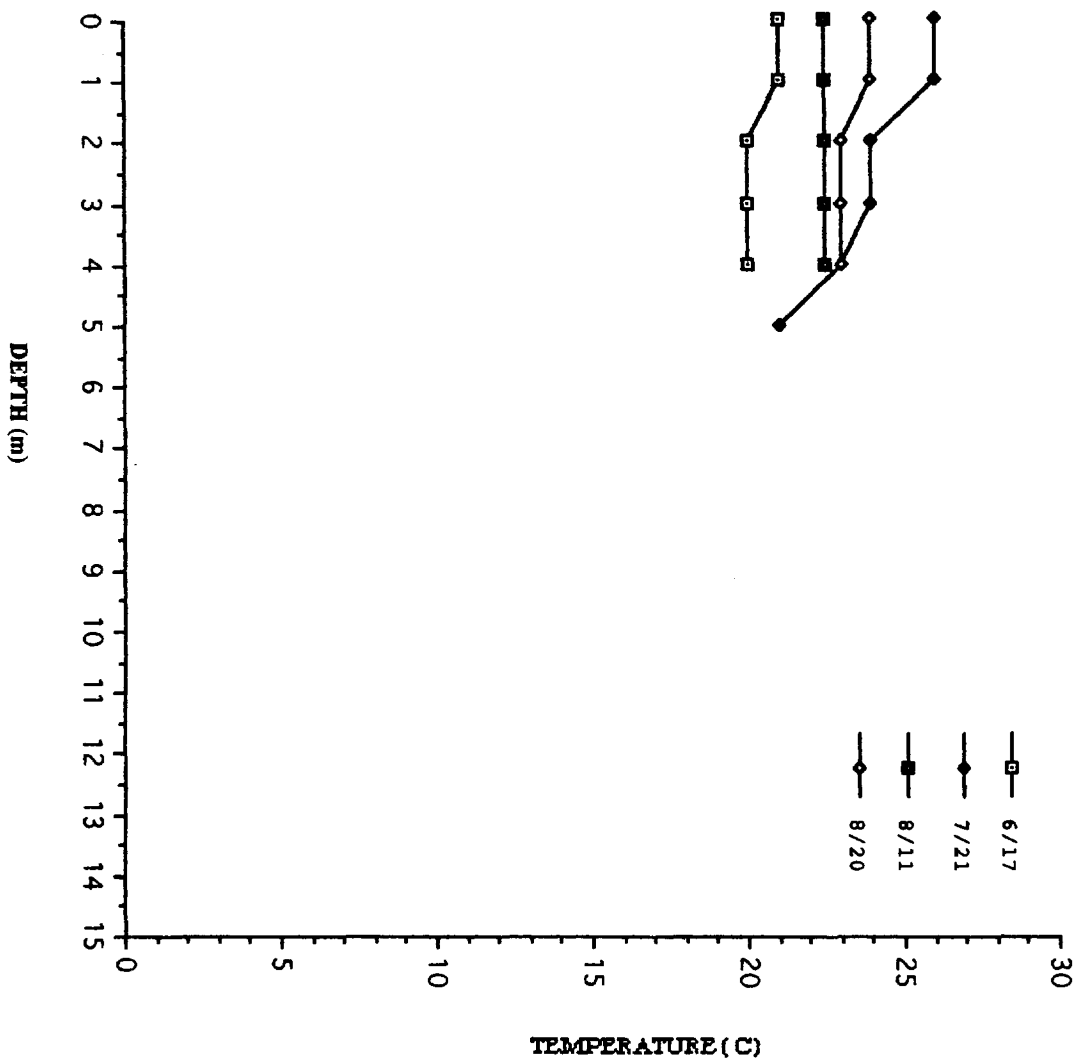
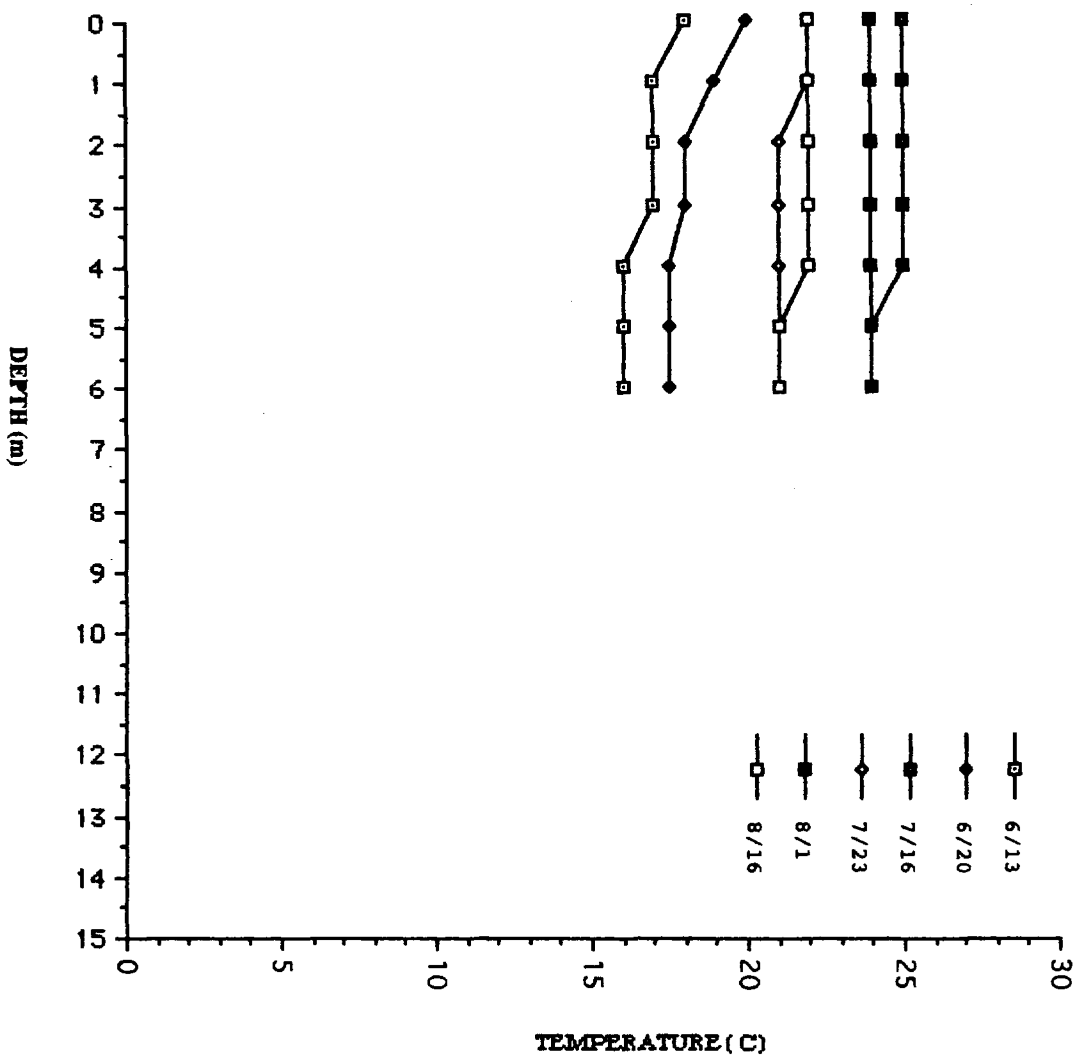
10
15
20
25
30
6/18
7/22
8/4

1987



1989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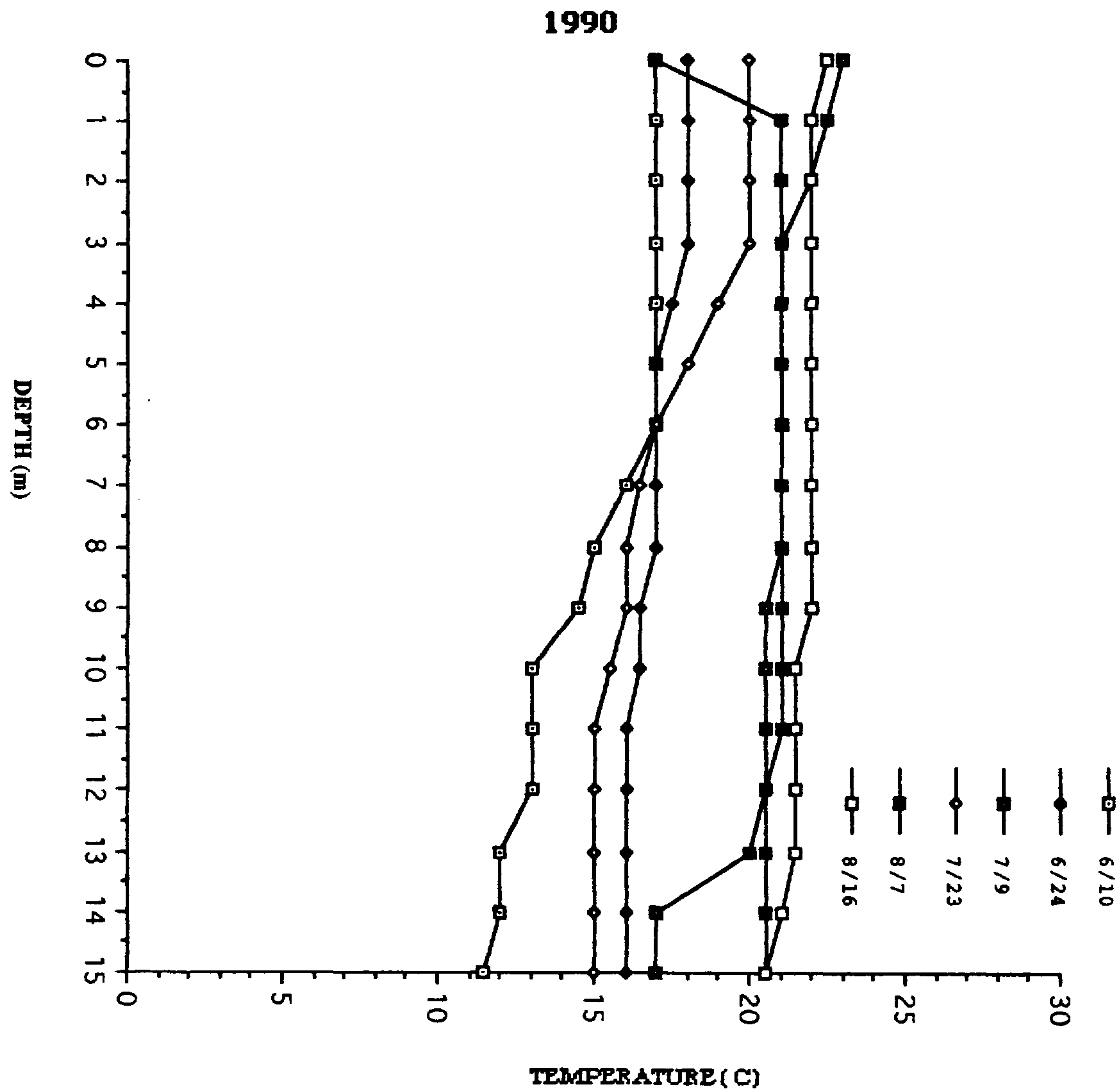
7/16
6/20
6/13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DEPTH (m)
TEMPERATURE (C)
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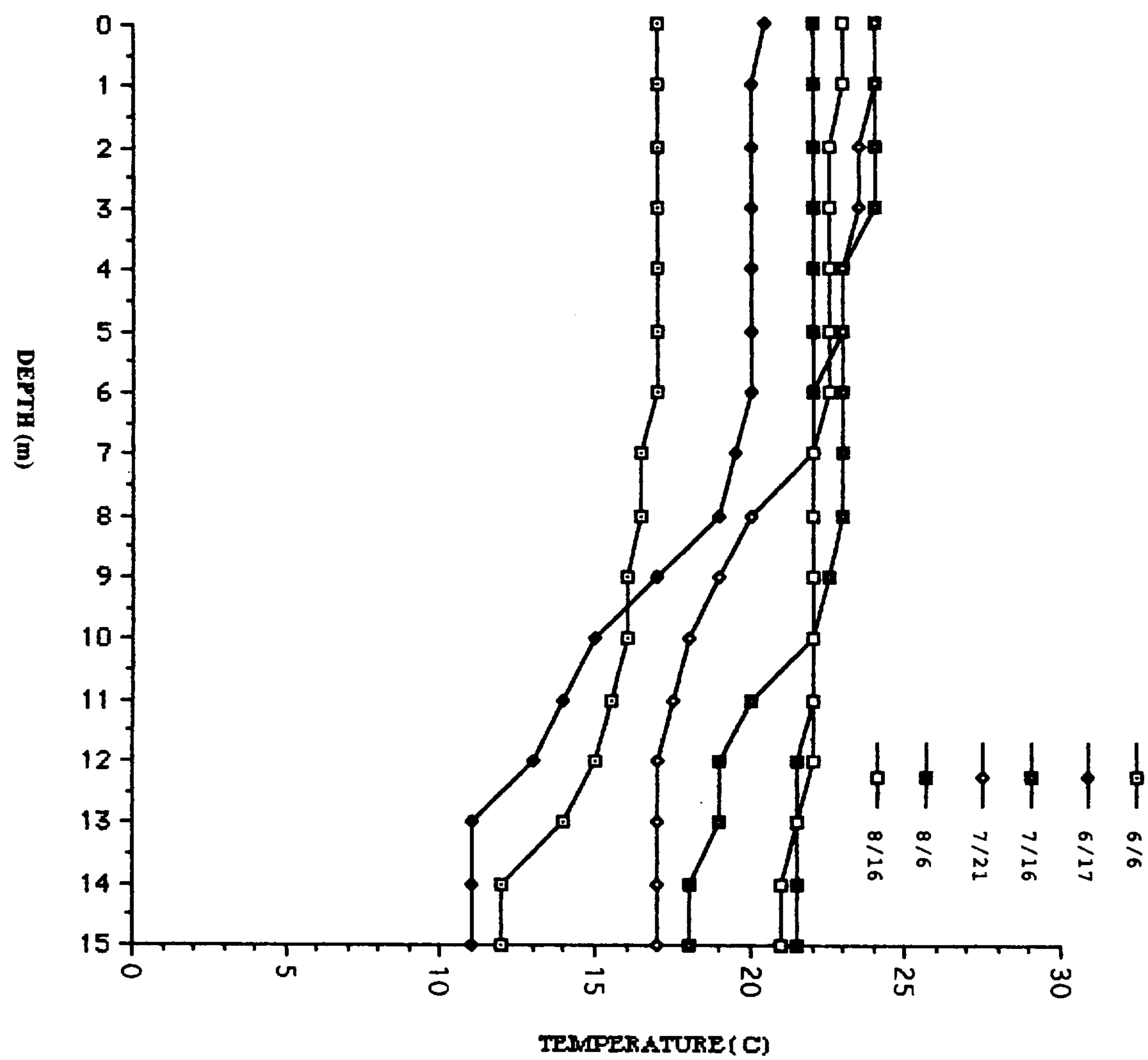
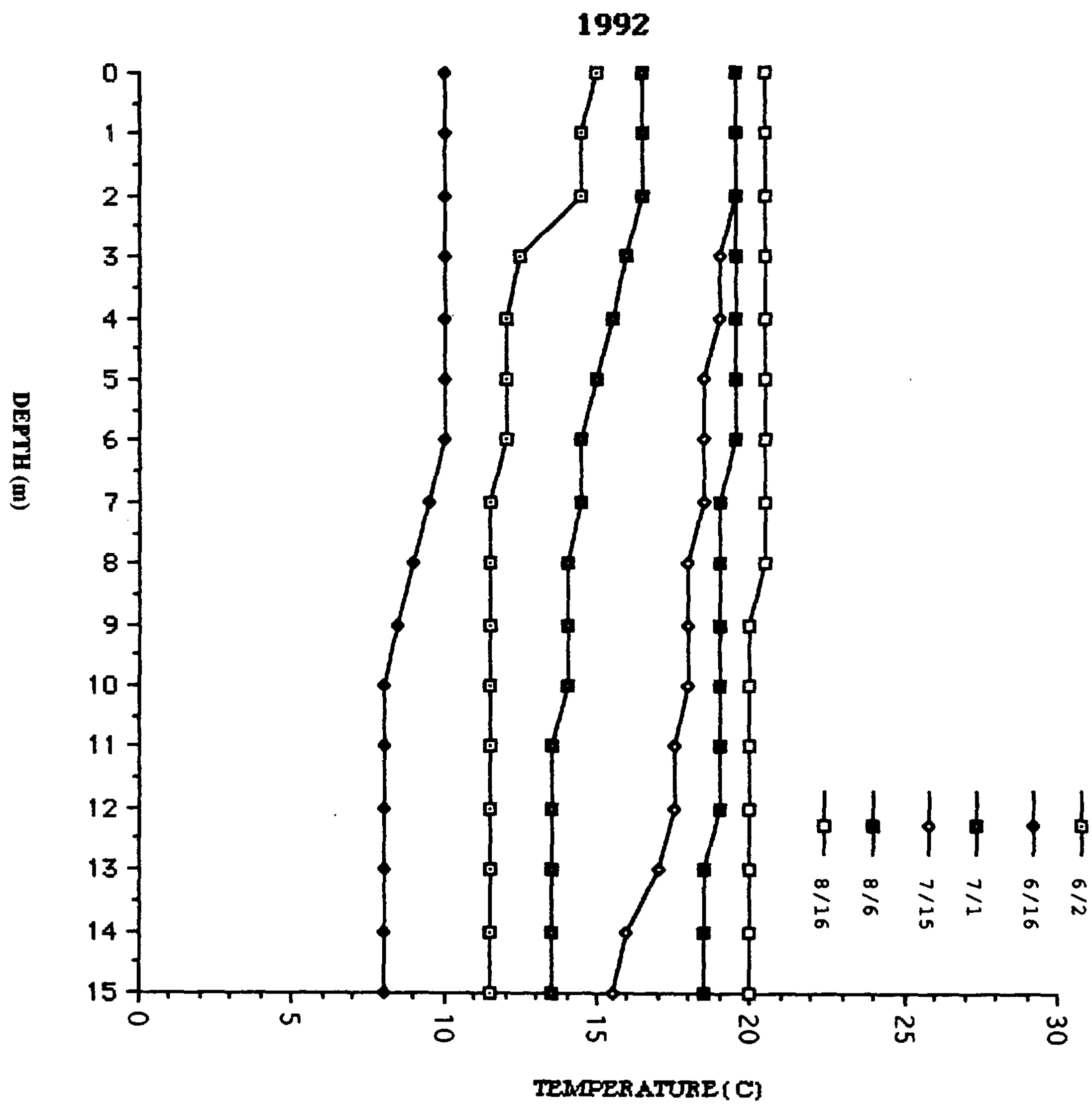
6/24
7/9
7/23
8/7
8/16

1991




1992
DEPTH (m)
TEMPERATURE (C)
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0 5 10 15 20 25 30
6/2
6/16
7/1
7/15
8/6
8/16